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CARRYING CAPACITY OF GRAZING RANGES IN SOUTHERN ARIZONA.

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INTRODUCTION.

This bulletin presents the results of several years' experimentation and measurements leading to the determination of the carrying capacity of certain kinds of stock ranges in southern Arizona. The climatic and soil conditions under which the experiments have been carried on are those of the lower foothills and the sloping belt of grassland 8 or 10 miles wide which surround all the mountains of that region. The altitudinal variations are between 2,800 and 5,500 feet. All the area studied has been under control and observation for 11 years. Forty-nine sections which were badly run down by overstocking at the beginning of the study have been under a condition of complete rest from stock. Approximately nine additional sections (the most productive part of the area) have been grazed according to the judgment of four men who are acquainted with the region. Three of these men have been in the business of raising cattle; the fourth has had a few head of horses and burros in his pastures. The policy of each of the cattle raisers has been to stock his area as heavily as it would bear, allowing a small margin for slow improvement. The nicety of adjustment of the various factors involved in such a plan has depended upon each man's judgment of what was the best thing to do under all circumstances. By this arrangement the pastured area inside the fence has been subjected

to as nearly the same treatment as the adjacent unfenced range received as was possible under the circumstances. When these experiments were begun in 1903 the problems which presented themselves for solution were as follows:[1]

(1) To demonstrate that under proper treatment run-down and overstocked ranges will recover, a statement of fact that was very much doubted by stockmen when the experiments were begun.

(2) To ascertain how long a time is necessary to get appreciable and complete recovery, and what methods of management will produce such results.

(3) To carry on reseeding and introduction experiments in the hope of increasing the total quantity of feed.

(4) To measure as accurately as possible the carrying capacity of a known representative area.

Results have already been published[2] relating to the first three of these questions. The present bulletin presents the data on carrying capacity which have been obtained so far. The methods of making collections originally established[3] have been continued. Hay-cutting operations have been carried on for five years, and records of the number of "animal-days'" feed[4] used on measured areas of the reserve have been obtained by recording the number of stock on given areas for a period of seven years. From the hay-cutting records and the estimates based upon the collections an estimate of the carrying capacity is made, and this is compared with the actual results obtained from the pasturing records. Some additional miscellaneous observations relating to the project are included.

The generalizations presented here apply strictly to the area indicated on the map. They could be applied without modification to exactly similar localities and conditions. They doubtless present a statement of conditions closely similar to those on many other parts of the southwestern arid grazing land; they will be usable with but slight modification over most of southern Arizona, and to some extent in New Mexico and western Texas.

Three maps of the area studied are given for the better understanding of the region. One of these (fig. 1) presents the main relief features of the reserve, being based upon the Patagonia quadrangle of the United States Geological Survey contour map of the Santa Rita Mountain region. Another is an outline map (fig. 2) that shows where collections of material were made. The small letters (without accent) refer to the spring collections made in the years 1903 to 1908, inclusive. The accented small letters refer to the

[1] See Bureau of Plant Industry Bulletin 67, preface.

[2] See Bureau of Plant Industry Bulletins 67, 117, and 177.

[3] See Bureau of Plant Industry Bulletin 67, p. 24 et seq.

[4] As used in this bulletin, an "animal-day's" feed equals the feed necessary for one mature animal, cow, steer, bull, horse, or burro, for one day. Calves or colts when six months old are counted as mature animals, but are not counted at all before that time.

fall collections of the same years. Figures without circles show the location of spring collections and those in circles show the locations at which fall collections were made during the years 1912 to 1914, inclusive.

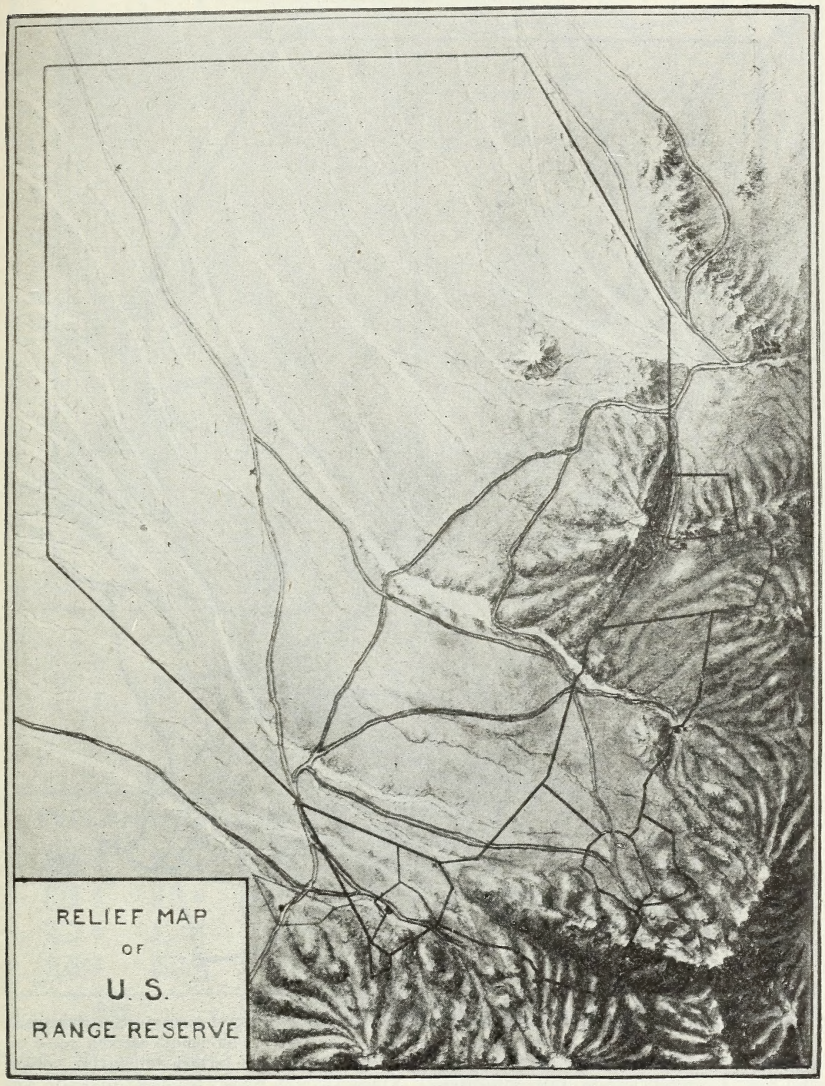

FIG. 1.—Relief map of the Santa Rita Range Reserve, Ariz., and some of the territory immediately surrounding it.

The plant-distribution map (fig. 3) is designed to put on record an approximation to the present distribution of the principal groups or associations of forage plants upon the reserve. Its use will be appreciated in the future study of the reserve if different adjust-

ments of the plant associations take place as the result of any particular kind of treatment. It does not rest upon accurate surveys, but is the best approximation which could be compiled by continued ob-

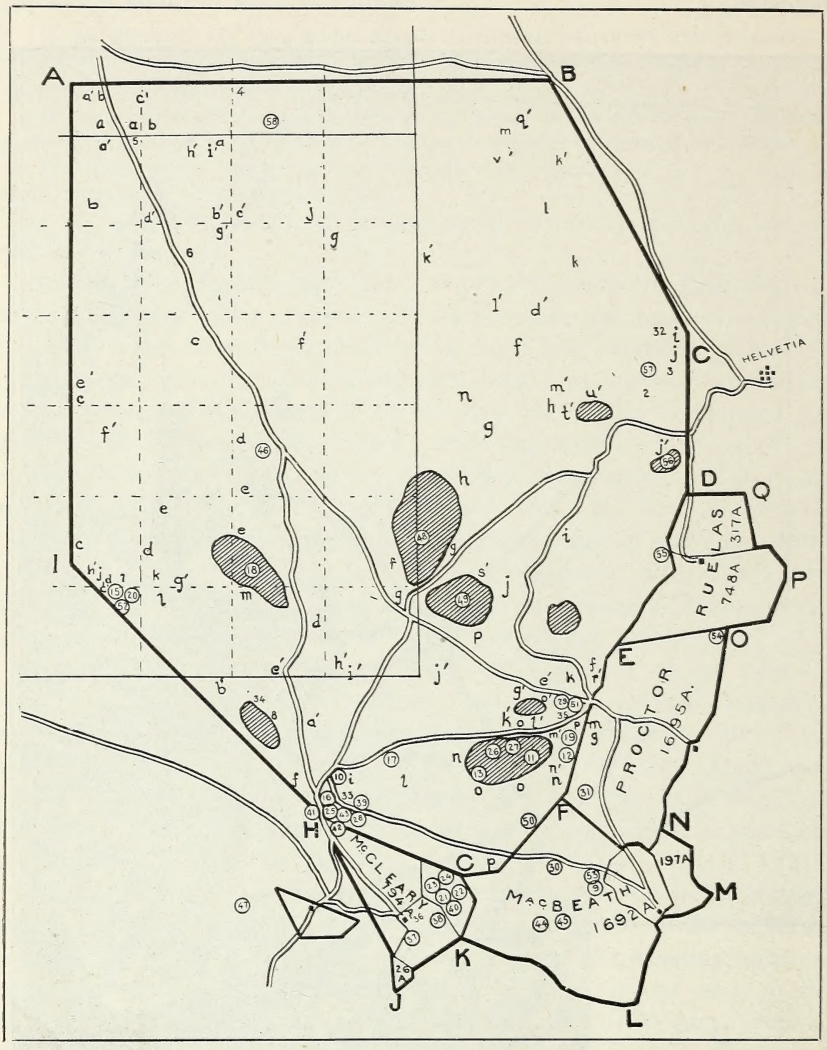

FIG. 2.—Outline map of the Santa Rita Range Reserve, Ariz., showing where quadrat collections have been made and where hay has been cut. The small letters refer to collections made from 1903 to 1908, inclusive, the unaccented letters indicating spring and the accented letters fall collections. Likewise, the small figures refer to collections made from 1912 to 1914, inclusive, the figures without circles indicating collections made in the spring and figures in circles fall collections. The shaded areas show where hay has been cut. The capital letters are introduced for convenience in reference.

servations and study made while riding over the reserve in all directions twice a year for the past three years. It is not a strictly ecological map, though some of its areas approximate the plant zones of the region. There is no doubt that the natural distribution

areas of certain species, and probably of the associations, had been much displaced by the previous grazing conditions to which the

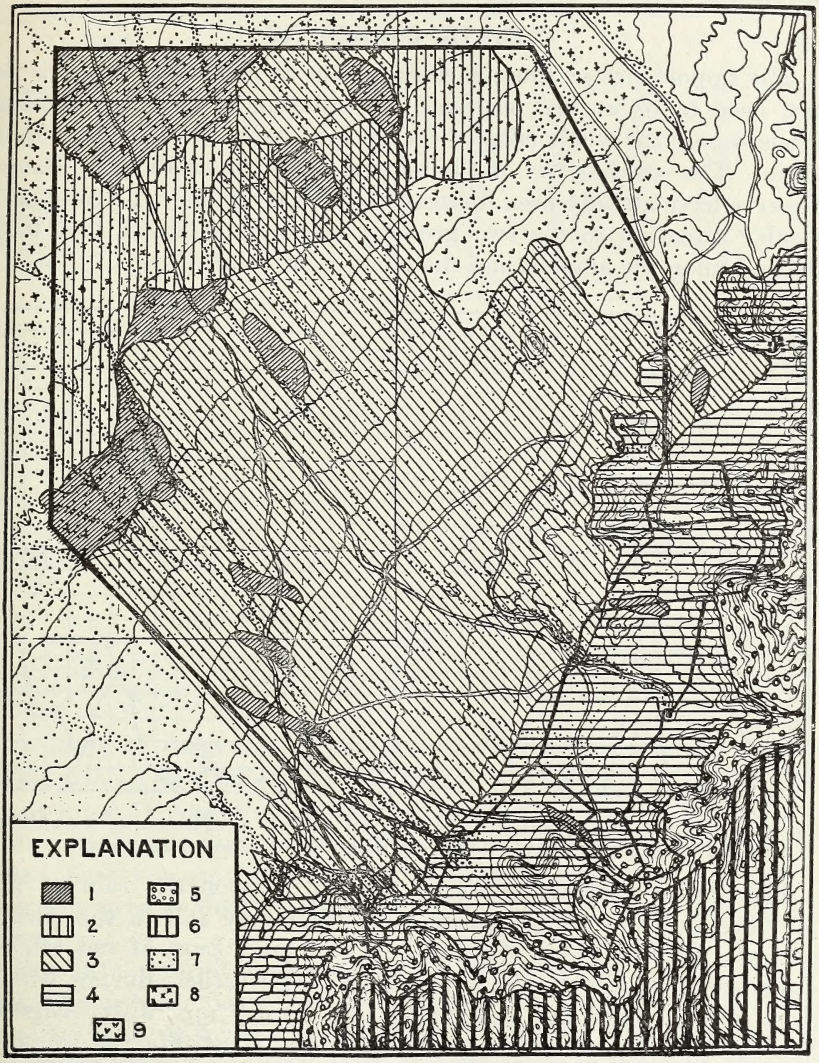

FIG. 3.—Map of the Santa Rita Range Reserve, Ariz., showing the present distribution of the principal forage-plant associations: No. 1, The six-weeks-grass association. No. 2. The black-grama association. No. 3. The crowfoot-grama association. No. 4. The needle-grass association. No. 5. The oak belt. No. 6. The forested area. Those parts of the reserve upon which the mesquite (*Prosopis velutina*), the cat's-claw (*Acacia greggii*), and other shrubs or low trees occur, more or less abundantly, are indicated by dots (No. 7) on the map. In the same way, the crosses (No. 8) and the check marks (No. 9) show where the tree cactus (*Opuntia spinosior*) and the cholla (*Opuntia fulgida*) are important members of the plant associations (Pl. I, fig. 2).

region had been subjected, and that under the protection of the fence these plants have been and are still readjusting themselves to the normal ecologic conditions. Maps of this kind made at various in-

tervals should show something of the changes taking place, and the more accurately they can be drawn the more valuable will be the information obtainable from such a series.

CLIMATIC CONDITIONS.

The importance of those factors known as climatic conditions do not need to be argued, especially in relation to the arid grazing lands, where the whole crop of forage is so patently dependent upon them. The peculiarities of the seasons upon the Santa Rita Range Reserve have already been discussed by Dr. Griffiths,[1] who calls particular attention to the two growing seasons and shows that they depend upon the amount and distribution of rainfall.

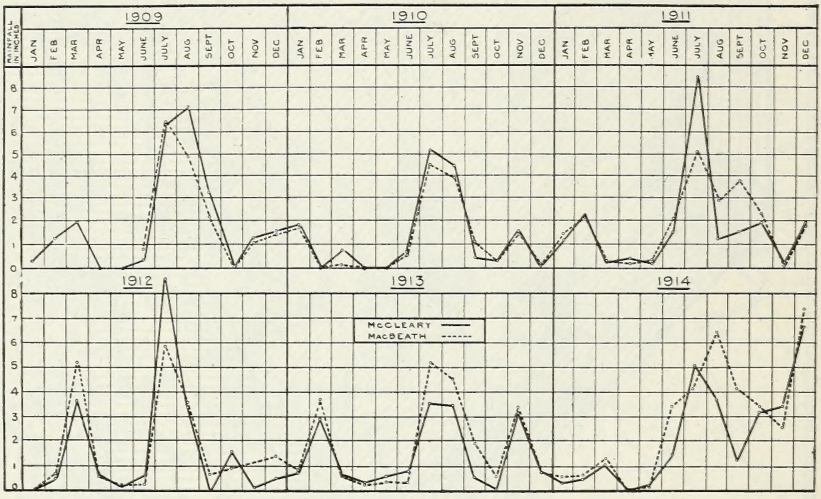

FIG. 4.—Curves showing the variations in the total monthly precipitation at two stations on the Santa Rita Range Reserve, Ariz., through a period of six years.

The spring growing season is dependent upon the rain of the previous fall and winter, taken with what may fall in the spring proper. In April and May, and in at least a part, if not all, of June, there usually occurs a period of dry weather, during which most growth ceases and the spring annuals dry up. July, August, September, and sometimes part of October constitute the summer growing season, since it is during this period that the greater part of the rain falls and, the temperature being high, rapid growth occurs.

Records of the rainfall by months at McCleary's house have been kept since July 1, 1901. In June of 1909 a rain gauge was placed at MacBeath's house and the records from both these stations are given in Table I. A comparison of the two records by months is shown in the diagram (fig. 4).

[1] See Bureau of Plant Industry Bulletin 67, pp. 38–44.

TABLE I.—*Precipitation, in inches, at MacBeath's place and at McCleary's place, Santa Rita Range Reserve, Ariz., by months, 1909 to 1914, inclusive.*[1]

MACBEATH'S PLACE.

Month.	1909	1910	1911	1912	1913	1914	Average.
January	.....	1.69	1.40	0	0.93	0.60	0.92
February	.....	0	2.03	.70	3.71	.75	1.44
March	.....	.13	.26	5.18	.60	1.29	1.49
April	.....	0	.18	.62	.23	0	.20
May	.....	0	.38	.24	.40	.05	.21
June	0.85	.57	2.04	.27	.42	3.44	1.27
July	6.45	4.64	5.05	5.89	5.15	4.09	5.21
August	4.90	3.94	2.96	3.69	4.58	6.48	4.43
September	2.17	1.02	3.79	.70	1.94	4.08	2.28
October	0	.26	2.27	.99	.58	3.45	1.29
November	1.03	1.43	.04	0	3.33	2.56	1.90
December	1.36	.18	1.83	1.38	.82	7.39	2.16
Total	.....	13.86	22.23	19.66	22.69	34.18	22.80

MCCLEARY'S PLACE.

January	0.28	1.71	1.15	0	0.86	0.37	0.73
February	1.22	0	2.06	.58	2.98	.55	1.23
March	1.98	.81	.21	3.64	.62	1.09	1.39
April	0	0	.38	.65	.30	0	.22
May	0	0	.16	.20	.60	.08	.17
June	.30	.69	1.51	.56	.86	1.55	.91
July	6.40	5.10	8.40	8.63	3.64	5.03	6.20
August	7.03	4.41	1.17	3.49	3.51	3.74	3.89
September	3.21	.51	1.53	0	.67	1.21	1.19
October	0	.26	1.95	1.55	.02	3.11	1.15
November	1.12	1.55	.10	.10	3.11	3.40	1.56
December	1.40	.16	1.91	.48	.83	6.67	1.91
Total	22.94	15.20	20.56	19.88	18.00	26.80	20.55

[1] The observations recorded in this table were not made by regular United States Weather Bureau observers, though United States standard rain gauges were used. The readings were made with the standard measuring stick between 6 and 8 o'clock the morning after the rainfall occurred.

A study of these data shows that the average annual rainfall at MacBeath's (elevation about 5,000 feet) has been about 11 per cent greater for 5½ years than at McCleary's (elevation about 4,000 feet), although the two stations are only about 3 miles apart on a straight line. They also show that the precipitation by months at McCleary's has been greater than at MacBeath's 26 out of the 66 months of the record.

For 1914 records were obtained at Mr. Robinson's camp (elevation about 4,500 feet) that are valuable for comparison with the others. Records for the last four months of 1914 were also made at Rosemont (elevation, 5,000 feet), 9 miles away as the crow flies, on the other side of the mountain range. It is impossible to present the daily records for these different stations in any sort of diagram that could be printed here, but a study of the records by days brings out one or two generalizations which are of some importance.

The first and most noticeable of these is the exceedingly restricted areas over which the rain falls at any one time. It must be understood that the most of the rain that falls in the region, particularly that of the so-called rainy season of summer, comes as local showers

covering small areas. This general truth may be recognized any summer, since it is often possible to see several separate showers falling at the same time in different directions from the observer.

Another fact brought out by a study of the records is that, while the showers do not occur at the same time at the three stations, rain at one station is usually preceded or followed by rain at the others. In other words, while each shower is small in extent of area covered, the single shower is only one of many occurring in a period of time extending over several days, which ultimately fall on most of the area. The daily differences disappear when the monthly and annual totals are made up, and other facts appear when these are plotted as curves. By this method the seasonal character of the distribution for each station is shown, and the averages for a period of years bring out the difference due to elevation.

One further consideration must be kept in mind. The stations at which rainfall records have been obtained are all in the edge of the mountains, at elevations of 4,000 to 5,000 feet. The records obtained at MacBeath's are about typical for the upper edge of the pastured areas; those from McCleary's for the lower edge, which is at the same time the upper edge of the recovery pasture. The lowest part of the recovery pasture is about 8 miles from the mountains, toward the middle of a wide bolson, or basin, and 1,000 feet lower in altitude. It therefore does not get the same amount of rainfall as that received at McCleary's, the nearest station. The only other station from which we have records bearing upon the problem is that of Tucson, 30-odd miles to the north and 600 feet still lower down. What may be called the normal annual precipitation at McCleary's is about 17 or 18 inches. This amount falls upon about 16 sections (28 per cent) of the reserve. About 10 sections (17 per cent) of the reserve, most of which is pastured, gets about a 20-inch normal rainfall. Assuming that it is fair to interpolate between the normals for McCleary's and Tucson on the basis of altitude, we have 32 sections (55 per cent) of the reserve receiving a normal of something like 12 to 14 inches. Besides these general differences in precipitation, we have an increasing degree of annual fluctuation in amount of precipitation; a greater amount of evaporation, due to increased temperature; poorer soil protection by vegetation; and longer periods of desiccation as we go from the mountains toward the middle of the basin. All these factors are registered in the vegetation, both in its character and its quantity, and the summation of these differences affects most profoundly the carrying capacity of this region for stock. Snow in quantity, depending largely upon the elevation, occurs at rather rare intervals in the winter, but lies on the ground for only a short time. One of the heaviest snows for a number of years is shown in Plate I, figure 1.

FIG. 1.—VIEW IN THE OAK BELT ON THE SANTA RITA RANGE RESERVE, SHOWING AN OCCASIONAL WINTER CONDITION.

Such snows are quite infrequent and last but a few days at most.

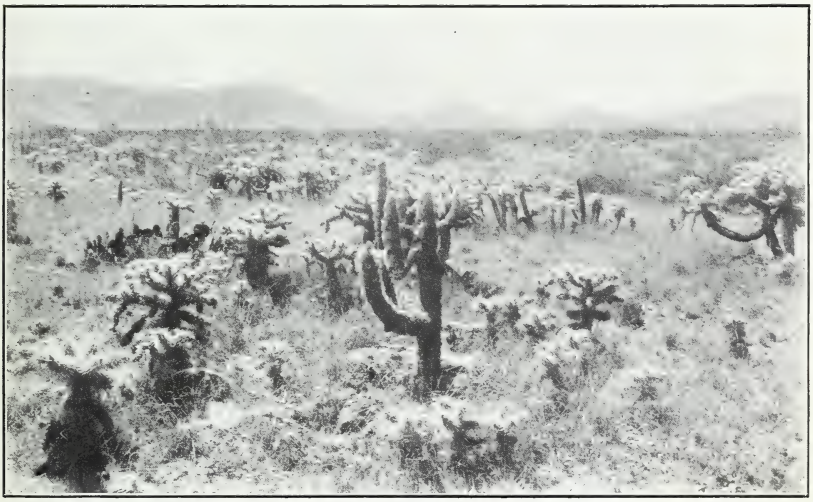

FIG. 2.—A DENSE STAND OF CHOLLAS (OPUNTIA FULGIDA) IN THE NORTHEASTERN PART OF THE RESERVE

FIG. 1.—A VERY DENSE STAND OF THE SIX-WEEKS GRASSES ON THE SANTA RITA RANGE RESERVE.

FIG. 2.—THE GENERAL APPEARANCE OF THE BEST OF THE BLACK GRAMA ASSOCIATION ON THE RESERVE.

CHARACTER AND DISTRIBUTION OF FORAGE.

Attention has already been directed to the variation in the average annual precipitation that occurs on different parts of the Santa Rita Range Reserve and its relation to the forage crop produced.

Protection from stock has allowed the plants of the greater part of the range to assume something like a normal adjustment among themselves and to the climatic conditions, and this adjustment has resulted in certain tolerably well-marked groupings of species of plants that cover areas of considerable size. Such assemblages of species, which have similar climatic and soil requirements and live together in a given area, are here called plant associations, and five of the principal associations are named. An attempt to map somewhat roughly the area covered by each, in order that the relative importance and productivity of each may be readily grasped, is shown in figure 3.

A more detailed description of these associations follows, in which the writer has attempted to give some idea of the character of the forage which they produce. Each association (except one) is designated by the name of its most important and most abundant grass. This species is not always the most noticeable or largest plant of its distribution area, but is the most important forage plant.

Plant associations selected upon this economic basis can hardly be expected to be the typical ecologic associations of the region, and a map setting forth these ideas is not an ecological map in the generally accepted sense. As a matter of fact, the major part of the attention is directed to the subdivisions of the grass zone of the region, and the areas represented are not of equal rank from an ecological standpoint. However, the economic consideration is of first importance here, and with these explanations the descriptions of what had better be called associations of forage plants may be taken up.

THE SIX-WEEKS-GRASS ASSOCIATION.

The dominant species of the six-weeks-grass association (No. 1 in fig. 3) are *Aristida bromoides* and *Bouteloua aristidoides*, short-season annuals, as is indicated by the common name. (Pl. II, fig. 1.) A grass that is usually referred to under the first name, but may be another species, makes a growth during the late spring before the early-summer dry spell, if there be sufficient spring rainfall, though this growth is often quite scanty. During the summer-growing period these grasses make surprisingly rapid growth and are very numerous on most of the bare ground at nearly any level on the reserve. They grow as thickly as they can stand, the stronger crowding out the weak, and all mature seed whether the season or the conditions be such as will produce a growth of a foot or only a few

inches. The certainty of producing a crop of seeds and the ability of these seeds to endure desiccation and to plant themselves are factors which probably account for the distribution of these grasses. They are easily crowded out by even the least aggressive of the perennials, yet they occur as scattered individuals among nearly all the other grasses almost any season, though this habit is not so well shown by the Bouteloua as by the Aristida. Wherever, for any reason, the perennial grasses are killed out these grasses occupy the ground for the short summer growing season.

The six-weeks grasses now occupy at least six or seven sections of the reserve as an almost pure stand, while they form a very important part of the assemblage here referred to as the black-grama association (No. 2 in fig. 3) and the crowfoot-grama association (No. 3 in fig. 3), especially along the boundaries of these areas. It is difficult to say definitely in many places just where the six-weeks grasses cease to dominate the association, and there is certainly no such well-marked boundary line between this association and those adjacent to it as is suggested by the more or less arbitrary divisions made in this bulletin. When the range reserve was first inclosed, this association was of greater extent than any other grass association in the reserve. It has been replaced primarily by the crowfoot-grama association from above, but the black-grama association has also crowded in from below, and the latter, while much slower in its encroachments and much more easily checked by grazing, may in the end dominate both the others if the area be protected for a sufficient time, especially if fire be prevented.

Considered as a forage crop and from the standpoint of their economic importance, the grasses of this association are not of great value. They produce a light crop of forage; the crop lasts but a short time and loses feeding value rapidly, being almost valueless by the middle of the winter; and for some reason (probably because the plants pull up easily and thus get dirt in the animals' mouths) stock do not eat them while at their best, unless there is nothing else to be had. However, the growth of spring annuals is usually heaviest on this area, and they add considerable good feed to the total annual crop.

THE BLACK-GRAMA ASSOCIATION.

Across the northwest corner of the reserve and extending along much of the west side is an area in which the most conspicuous grass is what is called "black grama" in this region (No. 2 in fig. 3). The grass in question is not a member of the genus Bouteloua, which contains what are usually called gramas, its scientific name being *Muhlenbergia porteri* (Pl. II, fig. 2). Its importance in the early days of the stock business in this region has been discussed by

Griffiths[1] and Thornber[2]. Certain characteristics of this grass need further emphasis, however, since by virtue of them it offers possibilities not shown by many other grasses of the region. It endures great extremes of temperature and dryness; it grows upon some of the poorest and driest of the gravelly mesa soils; it occurs at altitudes ranging from about 2,000 to over 4,000 feet; it is excellent feed; its stems are perennial and die back but a short way at the tip each winter, thus furnishing feed at any time in the year. These are its good points. It must be remembered that its growth is very slow, dependent entirely upon the water supply of a very dry region; that its seeding habits are poor, and that conditions for germination are poor even when viable seeds are produced; that it is easy to overestimate the carrying capacity of a previously unstocked range of this kind of grass, because the growth present is that of several seasons. These are the bad points. This grass usually occurs under the bushes and may be found sparsely scattered over all the mesa country in such protection. It certainly will not bear any degree of overstocking, but it is at least doubtful if students of grazing conditions (the writer included) are warranted in treating this grass as not worthy of much consideration, as has been very largely their habit hitherto.

The way that this grass (probably the best feed of its distribution area) has managed to persist in a region which has been thoroughly denuded of everything in the way of stock feed is of itself noteworthy. And observations in the reserve have demonstrated clearly that under protection from animals it is capable of dominating areas where it was thought to be almost a negligible factor. When the fence was first built it was hard to find any large plants of this species,[3] and they were always under bushes. After 11 years of protection it is fairly common all over the reserve below the 3,800-foot contour, and, while the old plants are more apt to occur in the bushes, their presence there is not universal nor due to the necessity of shade or protection, but probably because such situations are more favorable for the germination of the seeds. Within the past four years, since seed plants have become tolerably numerous, the species has spread quite rapidly in the northwestern quarter of the reserve and has put a considerable crop of good feed on an area that previously produced a very small crop of poor feed. And there is little doubt that under protection this plant will come to dominate much of the reserve, especially that part of it where the other perennial grasses grow but poorly. The spread and development of this plant under protection is strongly corroborative of the claims made for it by the

[1] See Bureau of Plant Industry Bulletin 177, p. 17.
[2] See Arizona Experiment Station Bulletin 65, p. 279.
[3] See Bureau of Plant Industry Bulletin 177, Pl. IV, fig. 1.

older stockmen of the region, claims that have seemed to the writer at times very hard to believe and very easy to discount at a high rate.

It is not intended to imply by what has been said that the black grama is the dominant plant of the area here called by its name. The area in question is largely covered by large shrubs, such as mesquite, cat's-claw, palo verde, and cacti of various kinds. Besides these, there are the spring and summer annuals occurring in greater or less profusion according to the season. The writer has not seen the abundance of *Atriplex elegans* mentioned by Griffiths[1] in the region, nor some of the other species referred to, but the amount of grass in that region has increased considerably. Besides the annuals, crowfoot grama has spread as far north as the north fence and is pushing westward.

Along the west fence, on the broken, gravelly ridges, considerable wire grama (*Bouteloua eriopoda*), some *Dasychloa pulchella*, and less six-weeks grass occur associated with the black grama. The wire grama is very much like the black grama in its habits as a plant and its value as forage, and the treatment which would suit the one would satisfy the other. The two together, if given a chance, would doubtless put a crop of forage on much of southeastern Arizona that is now quite barren, but a number of years of protection would be necessary to produce this result. This grass association now furnishes the most of the available forage over approximately seven sections of the reserve, an area on which it was very unimportant 11 years ago.

THE CROWFOOT-GRAMA ASSOCIATION.

The crowfoot-grama association is the most important association now occupying any part of the area studied, mainly because it occupies more than half of it (No. 3 in fig. 3). It now covers about 31 of the 58 sections under fence and is still slowly extending its borders west and north. It is also important as furnishing an amount of forage that is about an average of the production of all the different forage-producing belts or zones of the region. It thus becomes an approximate measuring rod for the estimation of carrying capacity for the region.

The association consists mainly of grasses, of which crowfoot grama (*Bouteloua rothrockii*) is the most conspicuous and certainly the most abundant, though by no means the only one (Pl. III, fig. 1). At all levels except the very lowest may be found more or less of *Bouteloua filiformis*, which is also an important component of the needle-grass association; and three of the needle grasses (*Aristida divaricata*, *A. scabra*, and *A. californica*) also occur in greater or less abundance in this association. Along the upper side of the

[1] See Bureau of Plant Industry Bulletin 67, p. 26, plats A and B; p. 28, plats A′, B′, and C′.

area and extending into the needle-grass area, Texas curly-mesquite grass (*Hilaria cenchroides*) and *Heteropogon contortus* are common, forming almost pure stands of small extent (Pl. III, fig. 2). The wire grama (*Bouteloua eriopoda*) also contributes considerable to the forage crop of this association, but has its own distribution limits; it frequently covers areas of a few square yards to the complete exclusion of everything else. Besides the grasses, there are various other herbaceous annuals and perennials that appear either in the spring or summer and add to the total crop. There is a scattering growth of shrubs like mesquite, cat's-claw, desert willow, etc., over most of the crowfoot grama area, thickest along the arroyos and toward the west and north, but usually not heavy enough to in any way affect the growth of the grass. These add an amount of feed of which we have no measurements, because they were not obtainable with any degree of accuracy. Prickly pears and chollas are quite abundant in places, but a heavy crop of grass tends to kill them out, probably because of occasional fires which sweep the grassed area.

Earlier reports have shown the rate at which this association took possession of the upper part of the reserve, and photographs show very clearly how well the grass has grown. Pictures recently taken indicate that the grass is even thicker and larger now, and observations show very definitely that within five years the boundary of the crowfoot-grama area has moved westward more than a mile at the south end of the reserve, and about 2 miles to the northwest along the Tucson road. In the north-central part of the reserve the characteristic plants of this association are now more numerous than those of the six-weeks-grass association clear to the north fence, though much black grama, six-weeks grass, bushes, and cacti occur here, and there is also considerable bare ground in the region. What will ultimately dominate does not yet appear, but the important factor is the aggressiveness of both the black-grama and the crowfoot-grama grasses. It has taken a long time for this improvement and spread to show, because there were few seed plants to start with, and germination conditions are so severe that only a few new plants were established each year, or at even longer intervals.

THE NEEDLE-GRASS ASSOCIATION.

The needle-grass association is the assemblage of plants which forms the grass belt along the foothills, covering approximately nine sections of the area under fence (No. 4 in fig. 3). It is not clearly marked off from the crowfoot-grama association, there being more or less overlapping both ways. The line on the map which separates the two areas is as nearly where the crowfoot grama ceases to be the most important grass and the needle grasses assume that im-

portance as the writer was able to locate it. It may be undesirable from some standpoints to try to separate these associations, but to do so has seemed to give a little clearer conception of the conditions existing on the reserve, even though the crowfoot grama will go higher and the needle grasses do go considerably lower and notwithstanding the fact that other grasses occur freely in both associations and seem to link the two.

The needle-grass association consists of a number of important perennial grasses, of which *Aristida divaricata* and what is probably *A. scabra* are the most abundant (Pl. IV, fig. 1), hence the name here suggested. The next most important grass is *Bouteloua filiformis*, which frequently makes up from one-fourth to one-third of the assemblage. Toward the upper limit of the belt this grass is apt to be replaced by *B. chondrosioides*. Hairy grama (*Bouteloua hirsuta*) also occurs on the rockier hills, and Texas curly mesquite (*Hilaria cenchroides*) is not uncommon at the lower side of the zone.

Wherever the needle-grass association is entirely killed out the six-weeks grasses and annuals first take the ground, and then the short-lived perennial gramas appear in abundance before the longer lived perennial Aristidas become established. As the greater part of this belt that is inclosed is grazed by cattle and horses, the various conditions mentioned may be found at different places in the different pastures. Wherever the stock congregate most the six-weeks grasses and annuals abound. Where this condition of local overgrazing is relieved some step in the sequence of complete replacement of the association occurs.

Additional perennial grasses in this association are Texan timothy (*Lycurus phleoides*), tall, or side-oats, grama (*Bouteloua curtipendula*), *Eragrostis lugens*, *Elionurus barbiculmis*, and *Trachypogon montufari*, while numerous spring and summer herbaceous annuals and perennials add considerable to the forage crop. The lower limit of these needle grasses is not the limit of the association, since they are common in patches in the crowfoot-grama association and follow down the dry watercourses, or arroyos, to the very lowest parts of the inclosed area. In many places in the crowfoot-grama association they may constitute as much as 25 per cent of the forage present on the ground. Whether or not they will gradually crowd downhill and finally replace the crowfoot-grama association remains to be seen, but at present the writer believes they require a little more water than the crowfoot grama and will hardly be able to entirely replace that association as it now exists on the reserve, no matter how long the area may be protected. No data are available relative to the crop of spring feed upon this area, but it is doubtless of no great importance except where overgrazing has occurred.

THE OAK BELT.

About one section of the land in the MacBeath inclosure lies in the zone of the oaks (No. 5 in fig. 3). The forage in this area is composed mainly of the grasses of the needle-grass association (No. 4 in fig. 3), with a diminution of the amount of perennial species of Aristida and an increase of *Bouteloua chondrosioides*, *B. hirsuta*, Elionurus, Trachypogon, and others. The oak trees are distinctive of the zone, and the young ones afford considerable feed as browse, as do a number of the other shrubs and some perennial herbs (Pl. IV, fig. 2). The precipitation of this belt is greater than that of any of the others, and there is no doubt that, including the browse and spring growth, the area produces more feed than the lower levels, though complete figures are not available to demonstrate how much more. This fact must be kept in mind in the comparison of the records of animal-days' feed produced on the MacBeath inclosure.

THE PLOWED AREAS.

In the summer of 1912 it was decided to plow areas of an acre in extent in different parts of the reserve and determine as far as possible the sequence and rate of the return of the plants after they had been completely killed out. The effects of the change in the soil conditions were also considered. Late in September, areas were selected, measured, and plowed. One acre was chosen in the best of the crowfoot-grama area near the south gate (at H, fig. 2), and another in the six-weeks grass area where rayless goldenrod (*Isocoma hartwegii*) was very abundant, near the southwest corner of the reserve (at I, fig. 2). Collections as nearly representative as possible were made on these areas (Nos. 15 and 16, fig. 2) before the plowing was done, and the hay on the acre (near H, fig. 2) was cut and weighed.[1] The plowing on the area (near I, fig. 2) was poorly done, so that the plants of Isocoma were not all killed, and it was plowed again more thoroughly and deeper (about 4 inches) in December, 1913. At this later date another acre was plowed near the gate (at H, fig. 2), the intention being to get a larger number of collections for comparison. Collections have been made on each of these plowed areas each year, and other collections have also been made on the unplowed land beside the plowed area near the gate. These collections (Nos. 16, 25, and 43, fig. 2) indicate the production of forage on the unplowed land, the average total production for the three years being approximately 1,018 pounds of herbage per acre, of which 601 pounds, or nearly 60 per cent, is grass. Of this grass 570 pounds, or 56 per cent of the total herbage, is perennial grass. Comparing these results with others derived from

[1] See record in Table IV, for 1912: Felix, 1 acre=750 pounds.

collections (Nos. 28 and 42, fig. 2) made on the area plowed in 1912 and those (Nos. 39 and 41, fig. 2) made on the area plowed in 1913 gives an average total production of 797 pounds per acre, of which 389 pounds, or less than 50 per cent, is grass, and of this grass 164 pounds, or slightly more than 25 per cent of the total herbage, is perennial grass. A spring collection on this area (No. 33, fig. 2) made the second spring after plowing shows no real spring plants at all and no grass growing. The plants collected were all small, green, and growing, or rather waiting for more water to continue their growth. They were all species that belong to the summer rather than the spring growth. On the unplowed ground near by the small spring annuals, Plantago, Gilia, Caucalis, Filago, etc., were very small and all dried up at this time and, except for a few *Gilia flocossa*, were none of them growing on the plowed land. The difference was doubtless due to the condition of moisture of the surface soil which existed at the time of germination, the amount of available moisture in the soil, and the depth of planting required by the different seeds. The grasses will almost certainly take possession of these plowed areas in a shorter time than they would on an overstocked range, since the plants all about the area will furnish plenty of seeds, and the soil's ability to catch and hold water has been increased considerably by the plowing. As the soil settles and grows more compact the smaller spring annuals may be expected to become abundant. The plowed area near the southwest corner (at I, fig. 2) produced a much smaller amount of available feed which was largely composed of annual grasses even before plowing. The average amount of feed as shown by the collections made in 1913 and 1914 is of the same order of magnitude as that of the unplowed ground, but has a smaller proportion of grass of any kind and almost no perennial grass. The rate at which this area will be invaded by the Isocoma will be of some importance. No seedlings of this species were found on the plowed land in September, 1914, though special search was made for them. There were numerous seeding plants in the vicinity and a few of them on the plowed area itself.

NATURE AND RATE OF THE RECOVERY.

A comparison of the condition of the fenced area as described by Griffiths at the time of its inclosure in 1903[1] with its condition in 1914, as given in this bulletin, brings out some interesting generalizations as to the nature and degree of recovery that may be expected upon overstocked and eaten-down ranges in this region when properly cared for. In 1903 the grasses were to be found in anything like a thick stand only as far north and west as a line con-

[1] See Bureau of Plant Industry Bulletin 67.

FIG. 1.—THE CROWFOOT GRAMA ASSOCIATION IN A TYPICAL FORM ON THE SANTA RITA RANGE RESERVE.

FIG. 2.—A PATCH OF HETEROPOGON CONTORTUS ON THE RESERVE, SHOWING THE HABIT, SIZE, AND DENSITY OF THIS GRASS AS IT GROWS IN THE CROWFOOT GRAMA ASSOCIATION.

FIG. 1.—A CHARACTERISTIC DISPLAY OF THE NEEDLE GRASS ASSOCIATION UNDER COMPLETE PROTECTION ON THE SANTA RITA RANGE RESERVE.

FIG. 2.—GRAZING CONDITIONS IN THE OAK BELT ON THE RESERVE.

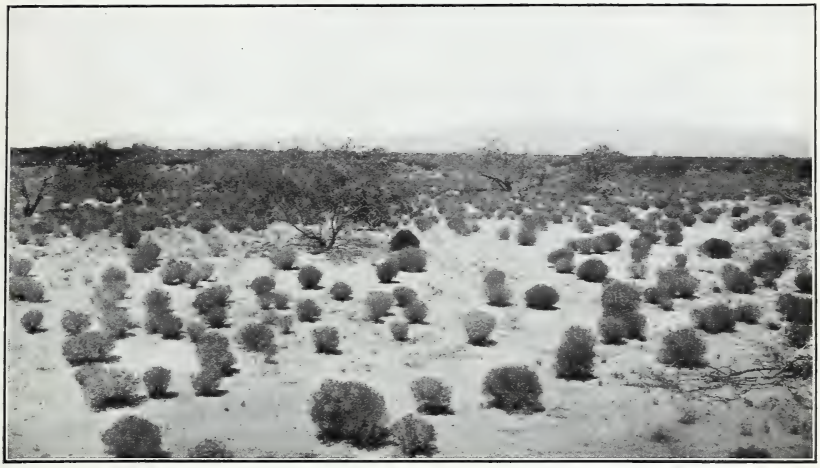

FIG. 1.—CONDITIONS IN THE SOUTHWEST CORNER OF THE SANTA RITA RANGE RESERVE IN 1903.

The rayless goldenrod is just beginning to occupy bare ground. (Compare with fig. 2.)

FIG. 2.—CONDITIONS IN THE SOUTHWEST CORNER OF THE RESERVE IN 1913.

The ground is almost completely covered with vegetation. Note the large amount of grass in the association; in 1914 a considerable part of the goldenrod was dead as the result of crowding by the grass. (Compare with fig. 1.)

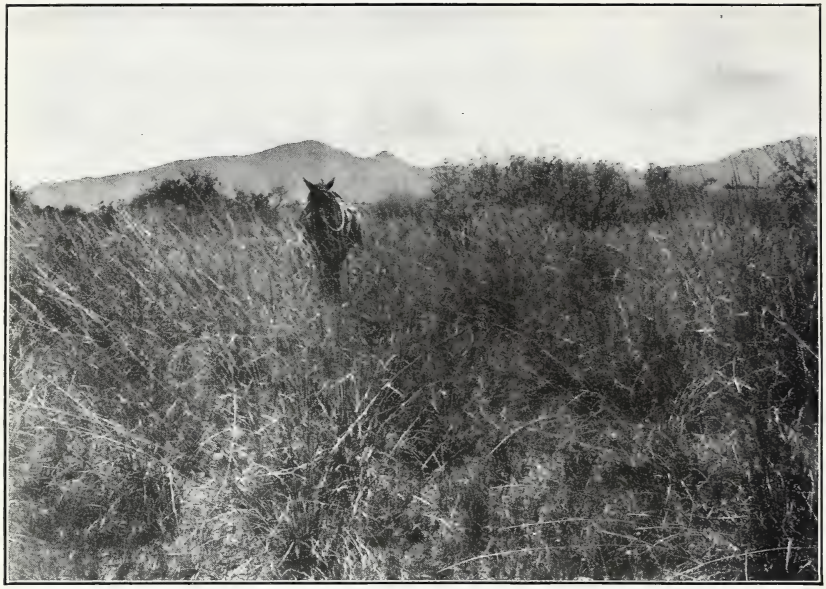

FIG. 1.—AN ALMOST PURE STAND OF DEER-GRASS (EPICAMPES RIGENS) ON THE SANDY SOIL OF ONE OF THE LARGER ARROYOS ON THE SANTA RITA RANGE RESERVE.

This grass is common in such situations.

FIG. 2.—AN ARROYO FILLED WITH MESQUITE, CAT'S-CLAW, AND OTHER SHRUBS ON THE RESERVE.

necting C and I on the map (fig. 2). It was difficult to find any black grama in the field.[1] In 1914 the perennial grasses had pushed northwestward along the Tucson road at least 1½ miles, if not 2 miles, farther than they extended about five years before, and were established about 1 mile farther west along the south side of the field. The crowfoot grama has reached the north fence, not as a pure stand, but as the most important element of a well-developed though not yet complete grass association. In this same area the black grama is now abundant and spreading. Along the west fence is an area where the black and wire gramas are becoming abundant and important. In the southwest corner is an area of a section or more where rayless goldenrod (*Isocoma hartwegii*) showed a scattering growth in 1903.[2] This same area is now thickly covered with large mature plants of this species (Pl. V, figs. 1 and 2), a large number of which are dying, probably as the result of the encroachment of the grasses which are gradually taking possession of the area.[3] The rayless goldenrod is of no value as a forage plant and it is customary to think and speak of it as a range weed and a nuisance. But it certainly protects the soil from erosion, retards run-off, and furnishes conditions favorable to the germination of the grass seeds. The grasses will probably eventually crowd it out.

One of the most noticeable features of the grass-covered area of the reserve is the prevalence of spots a few square yards in extent covered by an almost pure stand of some long-lived perennial grass. This habit is more or less characteristic of the black grama (*Muhlenbergia porteri*), but especially true of the wire grama (*Bouteloua eriopoda*), and of a coarse grass called *Heteropogon contortus* (Pl. III, fig. 2). The two first named are valuable forage plants; the last is usually considered undesirable.

Measurements show what is very plain to simple observation, that the Heteropogon puts a relatively large crop of feed on the ground. But this feed is almost valueless while green because the animals do not like it, and the grass is usually avoided in the hay cutting because of the large, sharp seeds that hurt the mouths of the animals. In 1914 about 100 pounds of this grass was cut and cured just before it commenced to seed. It made a very good quality of hay, which was eaten by one of the work horses with relish and in preference to old grama hay of the previous season. It would seem that this grass may have a possibility as a hay crop, if cut at the proper time. It is a long-lived, strong-rooted perennial that spreads by rootstocks and grows about 2 feet high.

[1] See Bureau of Plant Industry Bulletin 177, Pl. IV, fig. 1, photographed in November, 1902.

[2] See Bureau of Plant Industry Bulletin 177, Pl. IV, fig. 2, photographed in June, 1903.

[3] The comparative data here given are supported by the testimony of Mr. W. B. McCleary, who has known this range for the past 15 years and who drove over a large part of it with the writer in September, 1914, for the purpose of making comparisons.

Along the arroyos several grasses have taken possession, and the crop of feed they put on the margins of these dry watercourses is probably sufficient to render this broken land as productive of feed as the smoother areas (Pl. VI, fig. 1).

There is no doubt that the prediction made by Griffiths, that the mesquites and other shrubs would increase in size and number, is slowly coming true within the protected area (Pl. VI, fig. 2, and Pl. VIII, fig. 1). The only retardation they have received has been from the occasional fires, some of which have been severe enough to completely kill plants 10 to 12 feet high, though usually only the smaller bushes are killed back to the ground.

Along with the information relative to the general character of the changes taking place on a protected area, some data have been obtained as to the rate at which these changes take place.

The spring annuals and the six-weeks grasses occupy the bare land at once wherever there is sufficient rainfall. The recovery of the short-lived perennials was quite well advanced on this reserve after about three years' complete protection, and the area covered by them has certainly doubled in size in seven years' time. It has taken at least seven or eight years to bring about a condition favorable for the increase of the black grama, and this increase will doubtless continue for another 10 years before reaching its maximum. Yet much of the land, where this plant normally grows, would doubtless produce a crop of this grass where practically no forage grows now if it were given a period of complete rest for a few years and very light stocking for a number of years more. On the areas that have been carrying stock the recovery has been much less rapid, though very noticeable improvement has occurred.

CARRYING CAPACITY.

The method of making quadrat measurements, established by Griffiths,[1] has been continued by the writer since he has been connected with the work. The detailed reports of these records for the years 1903 to 1908 and 1912 to 1914, inclusive, are on file in the Office of Farm Management.

There is good reason to think that the areas now occupied by the crowfoot-grama and needle-grass associations, at least in that part of the reserve where these associations meet, has about reached its normal productivity under complete protection. Some further replacement and substitution of species may take place, but no marked change in the total productivity is to be looked for. As nearly as the writer is able to judge, this condition has existed, on the area mentioned, for the past three or four years.

[1] Reported in detail in Bureau of Plant Industry Bulletin 67, p. 25 et seq.

Assuming these conclusions to be correct we find in our results from quadrat collections data of sufficient accuracy for making estimates of the normal productivity and, therefore, the normal carrying capacity of ranges of this character. With these as a basis, still further generalizations relative to other forage-plant associations are also possible, since they may be derived from the ratios of productivity of the different areas as shown by the collections.

TABLE II.—*Average summer production of forage in certain parts of the Santa Rita Range Reserve, Ariz., as computed from the quadrat measurements made in 1912 to 1914, inclusive.*

Name of plant association.	Number of collections used.	Total herbage.	All grasses.		Perennial grasses.		All perennial plants.	
		Weight per acre produced.	Weight per acre.	Part of total.	Weight per acre.	Part of total.	Weight per acre.	Part of total.
		Pounds.	*Pounds.*	*Per cent.*	*Pounds.*	*Per cent.*	*Pounds.*	*Per cent.*
Needle grass	11	1,243	1,067	86	1,010	81	1,082	87
Crowfoot grama	23	1,045	972	93	864	83	932	89

Table II brings out an approximation to the relative productivity of the crowfoot-grama and needle-grass associations for three years, the former producing about 1,000 pounds of herbage per acre and the latter about 20 per cent more. This comparison may be a little unfair to the needle-grass association, since most of that area has been subjected to grazing, while the other has not. Another condition making against the accuracy of the comparison lies in the locations where collections were made. The 11 collections in the needle-grass association were mostly made near the lower edge of the area, where the effects due to the presence of stock are most noticeable. Of the 23 collections in the crowfoot-grama area, 18 are from the better parts of the area and only 3 are near its poorer boundaries. Thus the productivity of the needle-grass area as given is probably slightly below the average and that of the crowfoot grama is almost certainly a little above the average for its total area. They show nearly similar compositions, i. e., approximately 90 per cent of grasses, about 80 per cent of perennial grasses, and close to 90 per cent of perennials of all kinds.

Spring collections made in these areas have added very little to their total annual productions, though this would certainly be in favor of the needle-grass area, where no such collections have been made recently. Only seven spring collections have been made in the crowfoot-grama area, and they show a spring growth varying from 12 to 682 pounds per acre, the average of the seven being 178 pounds. Five of these collections, which were made after the summer growth began, show that the spring growth then constituted but a small part (from less than 5 per cent to about 33 per cent—77 per cent in

one collection) of the total vegetation on the area. In every case there was considerable perennial grass, never more than partly grown at the time of collection, thus increasing the apparent proportion of the spring growth. Estimates of the average productivity of the black-grama and six-weeks-grass areas, as made from the quadrat collections, would not be comparable with the results given in the table, mainly because neither of those areas has yet reached a state of normal productivity, and also because recent collections from these areas are not numerous enough to give fair averages. The only fall collection made recently in the black-grama area plainly gives too high a total production (1,210 pounds per acre) for an average annual productivity of that area. Another difficulty was encountered in making this collection, which applies to collections of wire grama also. These grasses do not die completely back to the ground in the winter; hence, it becomes very difficult to collect the growth of a single year, being absolutely sure that none of the growth of previous seasons has been included.

It will be very evident to the reader that the hay-cutting records are not directly comparable with the collections made on the quadrats. On the mowed areas the herbage obtained is only that part which can be cut by a mowing machine and picked up by a rake. On the quadrats every bit of vegetation above the surface of the ground was very carefully collected and weighed to an accuracy of 0.2 gram, a limit of accuracy which reduces to 1 pound of dried feed per acre. A number of collections were made on areas before they were mown and others on undisturbed areas besides the mown ones. While the number of these comparisons is not large enough to give a ratio which may be considered exact, the comparisons are at least quite suggestive. They are mostly easily seen in Table III.

TABLE III.—*Comparison of the total production of herbage per acre, as calculated from quadrat measurements, with the actual amounts of hay obtained from measured areas embracing or beside the quadrats, on the Santa Rita Range Reserve, Ariz.*

Location of cutting.	Data from quadrats.		Pounds of hay from 1 acre.	Percentage of total production obtained by hay-cutting operations.
	Quadrat No.	Total herbage in pounds per acre.		
Plat B, first cutting, near Proctor's camp (1.4 acres)	26	1,372	1,037	74.8
Plat C, second cutting, near old haystack (1 acre)	27	[1] 677	[1] 521	76.9
Ruelas in 1913	29	823	554	67.3
Felix in 1912	18	948	750	79.1
Felix in 1914	48, 49	876	794	90.6
Plowed acre near gate	16	1,609	750	40.6
Average		1,044	734	71.5

[1] The area was mowed the previous season, but no data were obtained. The collection represents the same growth as the hay cut, however, and they are therefore comparable.

Following is an attempt to estimate the total production on the fenced area. As computed from recent quadrat collections, the crowfoot-grama association produces about 1,045 pounds of summer forage and 178 pounds of spring forage per year, a total of 1,223 pounds per acre. The needle-grass association produces 1,243 pounds of summer growth and fully as much spring growth as the crowfoot-grama area, a total of 1,421 pounds at least. The productivity indicated by the single collection for the black-grama area, 1,217 pounds, is certainly more than an average, and the total annual production for the area is certainly not over 1,000 pounds per acre. The average production, as computed from the four spring and two summer collections from the six-weeks-grass area, is 871 pounds per acre. The remainder of the area does not produce over 400 pounds of forage per acre, if that much. A weighted average of the above figures, using round numbers, is as follows: Thirty-one sections of the first-named association at 1,200 pounds, 10 sections of the second at 1,400 pounds, 7 sections of the third at 1,000 pounds, 6 sections of the fourth at 800 pounds, and 4 sections of the last at 400 pounds. This accounts for the whole of the fenced area and gives an average production of 1,110 pounds of forage per acre.

An average of the total production of forage, as shown by the collections made in 1903,[1] 1904,[1] 1905,[1] 1907,[1] 1908,[1] 1912,[2] and 1914,[2] shows an average production of 1,160 pounds per acre. Thus two methods of computation reach practically the same result, which, in round numbers, may be taken at 1,100 pounds per acre as representing about normal productivity for this region.

If the figure representing average summer production on the crowfoot-grama area (1,045 pounds per acre), this being the area where all the hay cutting has been done, be compared with the average hay production (640 pounds per acre),[3] it is seen that the haying methods get roughly 60 per cent of the annual growth. Stock will gather a crop more closely than the mower, but not so closely as the quadrat collections were made. They probably do get from 75 to 80 per cent of the crop produced each season on the open range, and this includes the spring as well as the summer growth wherever the range is stocked to the limit.

It is equally true that even as close collecting as the haying operations make, at a time no more unfavorable to the plants than when the hay is cut, ultimately results in a marked reduction of the total amount of feed produced. (See Table V for effect of repeated

[1] See Bureau of Plant Industry Bulletin 177, p. 19.

[2] Totals obtained from averages of all spring and summer collections during these years on file in the Office of Farm Management.

[3] See Table IV, showing average weight of hay per acre. Table III gives actual comparisons on a few selected areas. The average result is probably too great.

cutting, p. 25.) Hence, in order to maintain productivity and prevent losses of stock in bad years, the range must be stocked at less than 60 per cent of its average productivity.

Assuming that a steer eats the equivalent of 30 pounds of dry forage per day, he will need about 11,000 pounds of forage in a year. If the average annual production of the grassed area is 1,100 pounds of dry forage per acre, then assuming that it is safe to put on enough stock to eat half of that amount annually, the average carrying capacity will be 20 acres per head per year if the range is to be maintained at its highest productivity.

THE MOST IMPORTANT FACTOR GOVERNING POSSIBLE IMPROVEMENT OF THE RANGE.

If it were possible to get a given area completely set in the best forage plants that would grow in the region, the productivity of the area would vary with the supply of water available to these plants during each growing season. All useless plants on such an area only waste the water which is so valuable for the production of feed. All run-off is complete loss of this precious moisture. It would seem to be desirable for a stockman to work toward the ideal condition as far as it is economically possible.

This is what the farmer in a humid region does, and he is able to modify and control the conditions on his farm only because the value of the product warrants the expense of its production. The stockman in the range country, whether his range be inclosed or open, is governed by the same principle, and on the open range he has the added uncertainty as to whether he himself will benefit by any labor he may expend in improving "his" range.

When it is remembered that much of the range land rents for 3 to 10 cents an acre per year without a fence, and that it requires from 15 to 50 acres to carry one cow through the year, one can appreciate how much may be expended economically upon the improvement of such land. It thus becomes apparent that the possibility of improvement rests entirely on a proper kind of management, and the possibility of the application of that management rests upon control. Yet there is a crop growing on this land and the cow has nothing to do but gather it. And if a man can get control of enough land, even of the poorest, and can get enough cows and other appurtenances of the business (Pl. VII, fig. 3), the output of meat animals, hides, wool, etc., will furnish him with a living. He may have to ride all over from 1 to 10 townships, but that is only an incident of the business.

HAY-CUTTING OPERATIONS.

STATEMENT OF CONDITIONS AND METHODS.

For the past five seasons—1910–1914, inclusive—hay cutting has been done in the protected area of the reserve and more or less complete records have been obtained. It must be kept in mind that hay cutting is possible over only a part of the protected area, and all of the hay cutting has been done upon selected areas where the conditions were the most favorable of any to be found in the field. Considered as a hay crop to be harvested, the forage produced on the reserve is at best so light as to raise some doubt as to the advisability of cutting it. And the conditions under which the work must be done are very unfavorable. Of the whole reserve, as indicated on the map, not over 20 sections of the ungrazed area receive enough summer rainfall to produce forage in sufficient quantity to be worth the cutting. And over much of this area the ground is too rocky or steep or broken or bushy to be mown. No water is available at any place inside the large field.

It follows that to do any hay cutting at all one must select an area of good grass land that is fairly level and free from rocks, bushes, and cacti. To this place must be brought the men, machinery, tools, wagons, etc., necessary for the work, and all the camp equipment and food necessary for the crew, both men and animals. Water for all camp purposes and all the animals, as well as grain feed, must be hauled to the camp, usually a distance of several miles. In nearly every case this outfit and crew have been brought from 15 to 20 miles, and most of the hay has been hauled the same distance (Pl. VII, figs. 1 and 2). And the roads of the region are nowhere very good for heavy hauling. It was impossible to bale the hay, on several occasions, because no baler was available. In a few cases the only available method of weighing the hay was by steelyards, and nearly all of the weighing was done, a bale at a time, on a small platform scale. In some of the larger cuttings the weight reported as the total is computed from the total number of bales and the average weight per bale of 15 to 25 bales actually weighed. The stacked hay was measured in all cases except two and the weight computed from the volume, which was obtained by the *F O W L* [1] rule and a weight factor to be explained later. The areas cut over were always quite irregular, but their acreage was obtained with a fair degree of accuracy in nearly every case. With these difficulties to be overcome, and the expenses entailed being limited by the economic possibilities of the situation alone, the records given in Table IV are submitted.

[1] See Bureau of Plant Industry Circular 131, entitled "Measuring Hay in Ricks or Stacks," p. 20.

TABLE IV.—*Record of all hay-cutting operations, Santa Rita Range Reserve, Ariz., 1910 to 1914, inclusive.*

Year and operator.	Total area.	Weight of hay.		Remarks.
		Total.	Per acre.	
1910.[1]	*Acres.*	*Pounds.*	*Pounds.*	
Felix	[2] 40	.....	504	A single representative acre, measured; hay weighed.
Ruelas	.....	.....	595	Do.
Do	.....	.....	1,045	A single representative acre, measured; hay weighed; old grass.
Proctor	.....	.....	1,475	Do.
Do	.....	.....	572	A single representative acre, measured; hay weighed; burned over.
Do	1	1,036	1,036	Measured acre (plat A) near middle fence; hay weighed; first time cut.
Brown	.....	.....	640	A single selected acre, measured; hay weighed.
1911.				
Ruelas	31	11,480	371	Hay all baled and weighed
Do	5.3	3,360	634	Do.
Do	12	5,834	486	Hay stacked and measured; weight computed by *F O W L* rule.[3]
Proctor	1	769	769	Measured acre (plat A) near middle fence; second time cut.
Do	1.4	1,482	1,037	Measured area (plat B) near Proctor's camp; weighed hay; first time cut.
Do	1	521	521	Measured area (plat C) near old haystack; weighed hay; cut over in previous year.
Do	29.9	.....	.....	Part of hay spoiled by continuous rain; total weight not obtained.
Nicholson	12	[4] 6,000	[4] 500	Hay stacked, not measured.
Brandt	33.5	17,240	514	Hay stacked and measured; weight computed by *F O W L* rule.[3]
1912.				
Proctor	1	463	463	Measured acre (plat A) near middle fence; third time cut.
Do	1.4	969	692	Measured area (plat B) near Proctor's camp; second time cut.
Do	1	441	441	Measured area (plat C) near old haystack; third time cut.
Do	21.5	14,802	688	Hay stacked for six months.
Felix	1	750	750	Measured acre; hay weighed; first time cut.
Do	112	81,000	723	Hay baled, 1,800 bales; average weight of 25 bales=45 pounds; total weight computed.
Lauterbach	5	[4] 3,000	[4] 600	Estimate based on weight of one load of loose hay.
1913.				
Ruelas	13.3	7,387	554	Measured area; hay baled and weighed.
Proctor	1.4	694	496	Measured area (plat B) near Proctor's camp; third time cut; hay baled and weighed.
Do	1	241	241	Measured acre (plat A) near middle fence; fourth time cut; hay baled and weighed.
Do	1	322	322	Measured area (plat C) near old haystack; fourth time cut; hay baled and weighed.
Do	9.8	6,556	669	Measured area; hay baled and weighed.
Do	21.9	15,596	712	Do.
Do	14.4	6,546	454	Do.
1914.				
Ruelas	28.6	.....	.....	Hay spoiled while waiting to be baled.
Do	6.9	.....	.....	Hay hauled in loose, not weighed.
Felix	114.2	90,717	794	Measured area; hay baled and bales counted; weight based on average of 65 bales weighed.
Proctor	1.4	526	376	Measured area (plat B) near Proctor's camp; hay baled and weighed.
Do	1	309	309	Measured area (plat C) near old haystack; hay baled and weighed.
Do	26.9	12,853	478	Measured area; hay baled and weighed.
Total	552.8	290,894	.....	
Average.	.....	.....	650	

[1] Measurements for 1910 made by Mr. H. H. Jobson.
[2] About.
[3] F=0.31, O=over, W=width, L=length of stack; 800 cubic feet of hay, stacked less than 30 days, =1 ton.
[4] Estimated.

Using all estimates as to weights and acreages, the average production per acre for five years has been 640 pounds of hay per acre.

Using the figures of only those instances in which the actual area is known and the total weight is also known gives an average of 558 pounds per acre. A comparison of these two figures would seem to indicate that probably some of the estimates were too high, thus increasing the average output of hay per acre for all cuttings. But a careful examination of the details of the records shows that it has so happened that all the records which show no element of estimate in them, except four, which are for small areas and therefore have little weight in the averages, are obtained from areas that have been mowed year after year for three to five years in succession, while many of the records which depend in any degree upon some one or more estimated factors are obtained from areas of medium to rather large size which were being cut for the first time. The hay from the latter kind of areas always contains a certain percentage of old grass which did not grow during the season that the hay was cut; hence, estimates of average production from such areas alone must be in excess of the average seasonal production. That estimates made from records of comparatively small areas which have been mown several years in succession must be somewhat under the average production will be seen by an examination of Table V, in which comparisons are given of the weight of hay cut from the same areas in successive years.

TABLE V.—*Comparison of the weights of hay cut on separate plats in successive years on the Santa Rita Range Reserve, Ariz.*

Number of cutting.	Plat A, near middle fence, 1 acre.			Plat B, near Proctor's hay camp, 1.4 acres.			Plat C, near old haystack, 1 acre.		
	Year.	Yield per acre.	Yearly decrease in production.	Year.	Yield per acre.	Yearly decrease in production.	Year.	Yield per acre.	Yearly decrease in production.
		Lbs.	*Per ct.*		*Lbs.*	*Per ct.*		*Lbs.*	*Per ct.*
First time	1910	1,036	.....	1911	1,037	.....	1910	(1)	.....
Second time	1911	769	25.8	1912	692	33.3	1911	521	.....
Third time	1912	463	39.8	1913	496	28.3	1912	441	15.3
Fourth time	1913	241	47.7	1914	376	24.2	1913	322	26.9
Fifth time	1914	.....	.....	.....	.....	.....	1914	309	4.0
Total decrease in productivity	4 years.	795	76.7	4 years.	661	63.7	4 years.	212	40.6

[1] Plat C was cut in 1910 along with the rest of the area, but the weight of hay on this particular acre was not obtained separately.

From Table V it will be seen that continued cutting of the grass, year after year in succession, causes a gradual but marked decrease of the crop, ranging in quantity from 4 per cent to nearly 50 per cent of the previous year's growth, the average annual decrease being about 25 per cent. The average total decrease in production on the three plats for a period of four years is 64 per cent of the crop

of the first year. Since the first cutting always contains some old grass, the actual reduction of forage due to repeated cutting is less than the amount indicated, but is certainly quite large.

Evidence not quite so conclusive is shown by the cuttings made by Mr. Proctor on the larger areas, probably less conclusive because it has been his habit to cut over some ground each year that had not been mowed before. Records for 1911 on the 29.9 acres were not obtained, because considerable of the hay was spoiled by rain. The average production in 1912 of 21.5 acres (most of which had been mowed the two previous seasons) was 688 pounds per acre. In 1913, 9.8 acres of this same land gave 669 pounds per acre, while 21.9 acres, part of which had not been cut previously, gave 712 pounds per acre. Early in June, 1914, a fire burned all the old grass in the region Proctor usually cuts, so there was no old grass to be had that season. The average production on the 26.88 acres that he cut that year was 478 pounds per acre, which is about 100 pounds per acre lower than the general average. Doubtless this was the result of the fire, which was more than normally effective because growth of the grass had already begun when it occurred. The records for the three years show a decline in productivity, which is doubtless attributable to continued cutting.

The only other factor which might influence these results would be the seasonal rainfall. From what has already been said about the "spotted" character of the rainfall, it follows that our records taken only a few miles away do not tell the actual facts with regard to the amount of water that fell upon these areas during the different growing seasons. But since the total seasonal rainfall on each plat was probably closely parallel to the records obtained at MacBeath's and at McCleary's, it is well to compare these figures for the different years under consideration. Since it is the seasonal rainfall only that affects the amount of forage here considered, it will be important to note the records of precipitation for June, July, August, and September, in the years 1910–1914, inclusive, as shown in Table VI.

TABLE VI.—*Comparison of summer rainfall records at two points on the Santa Rita Range Reserve, Ariz., 1910 to 1914, inclusive.*

Month.	McCleary's house.					MacBeath's house.				
	1910	1911	1912	1913	1914	1910	1911	1912	1913	1914
June	0.69	1.51	0.56	1.46	1.55	0.57	2.04	0.27	0.42	3.44
July	5.10	8.40	8.62	3.58	4.99	4.64	5.05	5.89	5.15	4.09
August	4.41	1.17	3.49	3.51	3.79	3.94	2.96	3.69	4.59	6.48
September	.51	1.56	0	.67	1.21	1.02	3.79	.70	1.94	4.08
Total	10.71	12.64	12.67	9.22	11.54	10.17	13.84	10.55	12.10	18.09

It is thus shown that while the growing season began a little earlier in 1911 and in 1914, there was sufficient rainfall each summer to produce the normal crop. But there is no continuous diminution of the precipitation from the first of the period to the last of it. In fact, 1914 was the rainiest year of the five, though all the plats show the least production during that year.

THE WEIGHT OF ARIZONA RANGE-GRASS HAY IN THE STACK.

The method used for the measurement of hay in stacks is to compute the volume of the stack and divide this result by the volume which weighs a ton of the given kind of hay. In computing the weight of Arizona range-grass in the stack, no data for obtaining this volume were available. In 1912, however, an opportunity for a single record was offered. That fall the press of other work made it necessary for Proctor to stack his hay and bale it later. The hay from 22½ acres was stacked and measured. In March, 1913, the stack was measured again and the hay was baled and weighed. Using the *F O W L* rule for computing the two volumes of the stack and dividing each by the total weight of the hay, it was found that of the newly stacked hay 861 cubic feet weighed 1 ton, while only 657 cubic feet of the old hay weighed as much. Since the first measurement was made when the hay was first stacked, it was assumed that 800 cubic feet of hay in the stack standing less than 30 days would weigh approximately 1 ton, and this factor was used in our computations. So far as the writer has been able to learn, this is the first record of definite measurements for the actual weight of Arizona range-grass hay in the stack.

THE COST OF MAKING RANGE HAY ON THE SANTA RITA RESERVE.

Only one set of records as to the cost of making range hay on this reserve has been obtained. In 1914 an area of 114.2 acres was mown which yielded 45.36 tons of hay. The crew required for the work was 8 men, a cook, and 6 horses. The machinery equipment consisted of 2 mowing machines, one 1-horse rake, one 2-horse buck rake, a baler, and 2 wagons, with the necessary harness, water barrels, and hand tools. The wages paid the men ranged from 75 cents to $1.25 per day and board, each man furnishing his own bedding. Allowing 25 cents a day per man for food, the total cost for food was $35. The grain and provisions came from the farm of the operator. The horse work done was as follows: 24 horse-days mowing, 12 horse-days raking, 20 horse-days bringing the hay to the baler, 20 horse-days baling, and 6 horse-days coming to the reserve, besides the necessary trips for water (3 miles and return for a load). The work required 12 man-days for the mowing, 12 man-

days raking, 10 man-days with the buck rake, and 95¼ man-days for the baling. The total expense for man labor was $122.35. Allowing 50 cents per day for a horse's work and his feed (which is about fair for the character of the teams and the amount of grain fed in this work), the horse work cost $41. Besides the regular provisions, a young beef worth probably $25 was killed and the meat used. The total cost of putting up 45 tons of hay was approximately $225, or $5 per ton. Two men, 8 horses, and 2 wagons were kept busy for 16 days hauling 40 tons of this hay to the home of the operator about 18 miles away, thus adding $2.40 more per ton to the cost of the hay. This allows nothing for depreciation on machinery, which should be quite heavy considering the character of the work. Some of this hay was sold at the baler before weighing, at the rate of $5 for 30 bales. The hay sold gave the operator about 50 cents per ton as net gain besides paying him $1.25 per day as wages and $1 a day per team for his animals, both of which prices are to be considered as good pay in the region for the character of the work performed.

GRAZING EXPERIMENTS.

The most instructive data so far obtained upon this reserve are those which have resulted from the actual carrying of stock on measured areas. Records have been kept as to the movement of stock on the pastures of four individuals for several years. From these records it is possible to compile: (1) The actual number of days' feed for one mature animal that each pasture has furnished each month, (2) the average number of animals carried by each pasture for each month and each year, and (3) the apparent carrying capacity of the areas for each year. These data have been summarized in Table VII and are visualized in figure 5.

The pastures have been handled independently by the users and according to the judgment of each man as to his own best method. The custom of the region (which had been followed by some of these men before, and continued by three of them since the area was placed under control) is to stock as heavily as the range will carry all the time.

TABLE VII.—*Stock grazed on individual pastures on the Santa Rita Range Reserve, Ariz., 1908 to 1914, inclusive.*

FELIZ RUELAS, OPERATOR.

Month.	Year.													
	1908		1909		1910		1911		1912		1913		1914	
	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.
January	.....	.....	2,709	87	2,044	66	2,697	87	2,170	70	2,904	94	1,860	60
February	.....	.....	2,652	94	2,352	84	2,436	87	1,960	70	2,688	96	1,464	52
March	.....	.....	3,397	110	2,604	84	3,172	102	2,170	70	3,548	114	1,333	43
April	.....	.....	4,660	155	2,052	68	3,360	112	2,100	70	4,554	147	1,290	43
May	.....	.....	5,937	191	2,833	91	3,274	106	1,855	60	4,290	138	990	32
June	.....	.....	5,350	178	2,002	67	2,820	91	1,050	35	1,080	36	1,140	38
July	.....	.....	3,875	125	1,085	35	899	29	899	29	1,116	36	1,178	38
August	.....	.....	1,685	54	4,495	145	1,155	37	1,371	44	1,116	36	1,298	42
September	.....	.....	3,150	105	2,250	75	1,350	45	1,710	57	1,506	50	1,740	58
October	.....	.....	3,400	110	2,629	85	1,775	57	1,763	57	1,581	51	2,533	81
November	4,500	150	2,100	70	2,730	91	1,350	45	2,214	74	2,135	71	3,015	101
December	2,743	89	1,876	61	2,821	91	1,845	59	2,604	84	1,860	60	3,348	108
Total	7,243	119	40,791	112	29,897	82	26,133	71	21,866	60	28,378	78	21,189	58
Acres per head[1]	6.3		8.6		13.0		14.8		17.8		13.7		18.3	

CHARLES A. PROCTOR, OPERATOR.

January	.....	.....	.....	.....	3,122	101	2,077	67	1,856	60	3,510	114	3,680	119
February	.....	.....	.....	.....	2,700	97	1,769	63	1,792	64	3,306	114	3,479	125
March	.....	.....	.....	.....	3,641	117	1,874	60	2,719	90	3,794	122	4,279	138
April	.....	.....	.....	.....	2,473	82	2,200	73	4,179	139	4,171	139	5,328	177
May	.....	.....	.....	.....	2,695	87	3,689	102	3,999	129	5,131	166	6,102	212
June	.....	.....	3,750	125	3,971	132	4,756	158	4,650	155	6,641	221	4,770	159
July	.....	.....	1,085	35	5,328	172	4,263	138	5,239	169	7,168	231	4,944	160
August	.....	.....	1,798	58	2,110	68	1,457	43	4,261	136	2,852	92	3,004	97
September	.....	.....	1,230	41	2,055	68	1,410	47	4,197	140	2,588	86	2,926	97
October	.....	.....	3,401	110	2,165	70	1,495	48	3,653	118	2,663	86	3,863	125
November	.....	.....	2,430	81	2,494	83	1,920	64	3,210	30	2,754	92	4,110	137
December	.....	.....	3,108	100	2,255	73	1,984	64	2,845	94	2,708	87	4,490	145
Total	.....	.....	16,802	78	35,009	96	28,894	77	42,600	110	47,286	129	50,975	141
Acres per head	.....		21.5		17.3		21.9		14.5		13.0		12.1	

W. B. MACBEATH, OPERATOR

January	2,083	67	3,874	154	3,729	120	5,278	170	2,045	66	2,150	69	7,292	235
February	2,320	80	3,747	134	3,316	107	4,872	174	2,576	89	2,397	86	6,182	221
March	3,050	98	4,686	151	3,736	121	5,747	186	3,714	120	3,249	105	7,693	248
April	3,409	113	4,905	158	4,840	161	6,921	231	3,510	117	5,613	187	8,396	279
May	3,660	118	5,192	167	5,628	181	7,216	233	4,253	137	4,429	143	9,020	291
June	4,290	143	4,990	166	6,417	214	7,033	234	4,890	163	6,626	221	8,785	293
July	4,153	134	5,040	163	6,325	204	6,449	208	5,526	178	8,494	274	8,029	259
August	3,948	127	4,470	138	5,786	187	4,375	141	2,865	92	5,167	167	3,221	104
September	3,240	108	4,247	137	4,565	157	3,300	110	2,454	82	3,494	116	9,150	65
October	3,418	110	4,340	140	4,557	147	2,656	86	1,608	52	3,031	98	1,565	50
November	3,247	108	3,630	121	4,485	149	1,946	65	1,654	55	5,365	179	1,200	40
December	3,205	103	3,705	120	4,828	156	2,139	69	1,674	54	7,302	236	2,128	69
Total	40,023	109	52,826	146	58,212	159	57,932	159	36,769	100	57,317	157	72,661	179
Acres per head	15.3		11.6		10.5		10.2		18.8		12.0		9.5	

[1] The figures in the line "Acres per head" show the average number of acres of land necessary to carry one mature animal one year. This result is found by dividing the total acreage by the average number of animals pastured.

TABLE VII.—*Stock grazed on individual pastures on the Santa Rita Range Reserve, Ariz., 1908 to 1914, inclusive*—Continued.

W. B. McCLEARY, OPERATOR.

Month.	Year.													
	1908		1909		1910		1911		1912		1913		1914	
	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.	Total animal-days' feed.	Average number of animals.
January	230	7	290	9	168	6	465	15	434	14	345	11	488	16
February	210	7	246	8	234	8	364	13	394	14	344	13	474	17
March	238	8	250	8	356	11	430	14	403	13	442	14	403	13
April	210	7	270	9	352	12	496	17	420	14	414	14	394	13
May	209	7	240	8	405	13	527	17	429	14	430	14	403	13
June	216	7	248	8	438	15	510	17	470	20	380	13	390	13
July	225	7	302	10	442	14	527	17	510	16	603	20	248	8
August	240	8	278	9	445	14	434	14	583	19	561	18	375	12
September	237	8	600	20	450	15	492	16	570	19	402	13	398	13
October	271	9	233	8	368	12	527	17	589	19	563	18	405	13
November	260	9	289	10	380	13	480	16	510	17	485	16	305	10
December	271	9	367	12	399	13	470	15	432	14	493	16	284	9
Total	2,817	7	3,613	10	4,437	12	5,722	15	5,744	16	5,462	15	4,567	13
Acres per head	103.1		80.2		65.6		50.9		50.5		53.2		63.5	

Since the fenced area available to each man is relatively small, and since each of them has just as much right to the use of the open range outside his fence as anyone, it has been their custom to watch the condition of the feed outside their pastures and the condition of their stock at all times and to carry their stock on the outside feed just as much of the time as possible. This policy causes them to turn out stock as soon as the feed outside warrants it, a procedure that results beneficially for the fenced pastures, because it allows the plants inside the fence to grow to the best advantage during the growing season. The control given by the fence makes it possible to save this feed until the outside feed is mostly eaten, when the stock can be brought inside on good grass. This method of treatment throws the greater part of the burden upon the outside range and tends to build up the carrying capacity of the inclosed area.

Under such a method, if the fenced area is stocked to its full capacity, but not overstocked, the carrying capacity derived from the numbers actually carried is probably a little in excess of what might be expected from the same land if stocked to its legitimate limit all the time. For this reason the carrying capacity indicated in Table VII and the diagram (fig. 5) may be a little too large. But this conclusion is not true if for any reason the pastures have not been stocked to their limit, or if they have been overstocked, either of which conditions may have arisen.

To understand these possibilities it is only necessary to call attention to two or three factors which would affect the result. If for any reason a pasture were understocked there would be excess feed on it, but the figures for average monthly and yearly numbers carried, as well as the average carrying capacity, would be lowered. Such a condition might arise if the stock-water supply should diminish or fail, a condition that did obtain for some time on the Ruelas place during 1913 and part of 1914.

If, because of exceptionally high prices, a man should sell a large part of his stock and not restock at once, or if, for any reason, he should be forced to sell or was unable to buy whenever his pasture warranted it, the number of animals on the pasture would be less

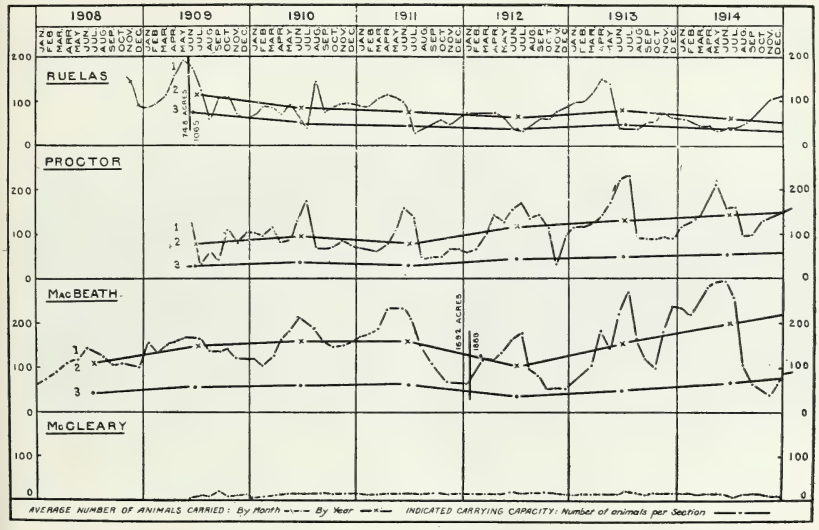

FIG. 5.—Curves showing variations in the rate of stocking on those parts of the reserve that have carried stock for the past six years. The curves numbered 1 show the average number of mature animals (cattle, horses, or burros) carried on each pasture, by months, for the full period. Curves numbered 2 show the same data by years. Curves numbered 3 show the average carrying capacity in acres per head per year for each pasture during the period of observation. Curves numbered 3 rest upon the assumption that the pastures have been stocked to their legitimate limit each year.

than it could carry, and all the figures relating to numbers carried and carrying capacity would again be below what the feed in the pasture might warrant.

Again, if the user should overestimate the capacity of his range and put on more stock than it could properly carry, the result would be an increase in all the figures, at least for a time, and a noticeable drop at a later period. Seasonal climatic variations of marked degree also would tend to decrease all values if unfavorable and to increase them if favorable to the growth of forage, though such variations would tend to counteract each other during a series of years.

There can be no question that the productivity of the areas which have been pastured is normally greater than the average for the whole inclosed area, because these pastures lie in that part of the grassed land which gets the most water. (See p. 8.)

The forage-distribution map (fig. 3) shows a small patch of six-weeks grass in each of the pastures, a condition which would seem to indicate that these pastures may be somewhat overstocked. The general opinion of the various men is that their pastures have improved under protection, and these poorly grassed areas may be the remnants of larger areas that are being gradually replaced, though more slowly than on the completely protected area.

In the opinion of the writer, the pastured areas have not deteriorated noticeably since July, 1911, nor have they materially improved. He believes that during that time they have been kept at about uniform productivity, but slightly below their maxima. The result of this is to make the carrying capacity appear a very little larger in figure 5 and in Table VII than it actually is.

The above remarks apply with most force to the MacBeath pasture, less so to the Proctor pasture, and hardly at all to the Ruelas pasture. It should be understood that McCleary has not been running cattle upon his pasture. He has had it lightly and about uniformly stocked with horses and burros. These animals have been on the land continuously with little or no shifting, and the range which was unable to carry stock at the rate of 29 acres per head in the earlier days of the experiments[1] is now not noticeably different from the completely protected area lying immediately north of it. It is hardly possible to tell by the condition of the grass that there is any stock on this area. From such data it is perfectly certain that 50 acres per head per year is considerably under the carrying capacity of such range pasture.[2]

It is almost certain that stocking heavier than 53 animals per section (12 acres per head per year) on the MacBeath place and between 45 and 50 animals per section (13 or 14 acres per head per year) on the Proctor place is not warranted by the present condition of these pastures, under their present form of management. It is more difficult to get an estimate for the Ruelas place, because other important but as yet unmeasured factors enter the problem. From the standpoint of feed alone, the Ruelas pasture will doubtless carry as much per section as the MacBeath place, but for some time past the supply of stock water has been insufficient for all the stock which the pasture would carry.

[1] See Bureau of Plant Industry Bulletin 177, p. 21.

[2] The horses on this area have very light work and little of it. They are always fed a small amount of grain whenever they are worked; at other times all their feed is the native grass grown on the area.

FIG. 1.—BALING HAY ON THE SANTA RITA RANGE RESERVE IN SEPTEMBER, 1914.

FIG. 2.—BALED HAY ON THE RESERVE READY TO BE HAULED TO A FARM IN THE VALLEY, 25 MILES AWAY.

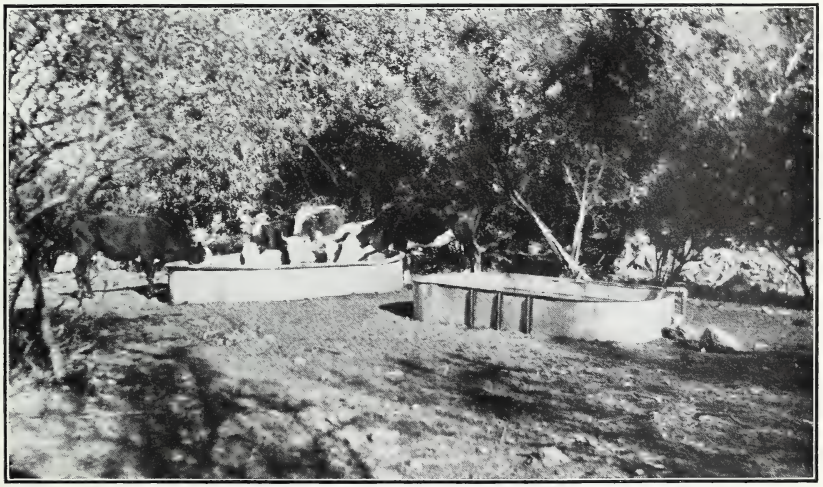

FIG. 3.—ONE OF THE WATERING PLACES IN MACBEATH'S PASTURE, ON THE RESERVE.

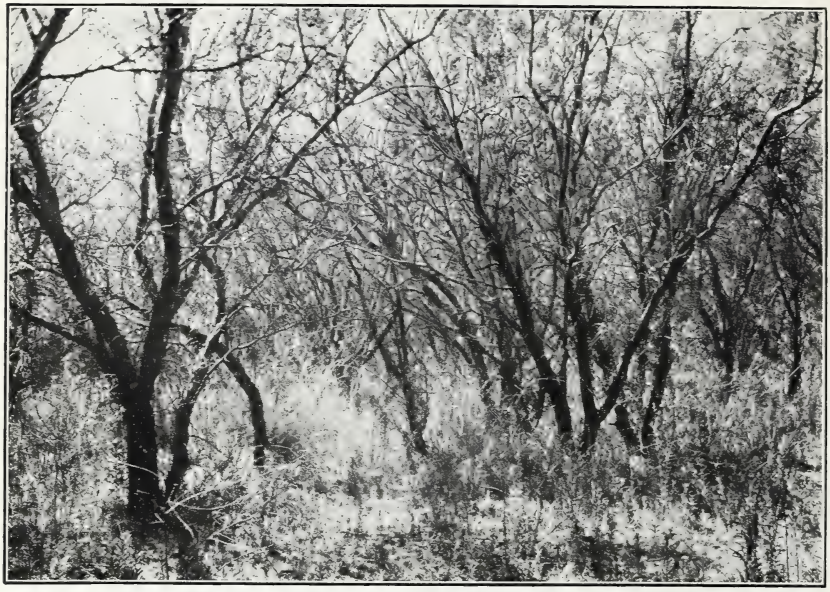

FIG. 1.—A DENSE GROWTH OF MESQUITE BUSHES IN STONE CABIN CANYON, ON THE SANTA RITA RANGE RESERVE.

Some stools of saccaton (*Sporobolus wrightii*) are shown near the center of the picture. This grass thrives where other grasses are killed by the shade.

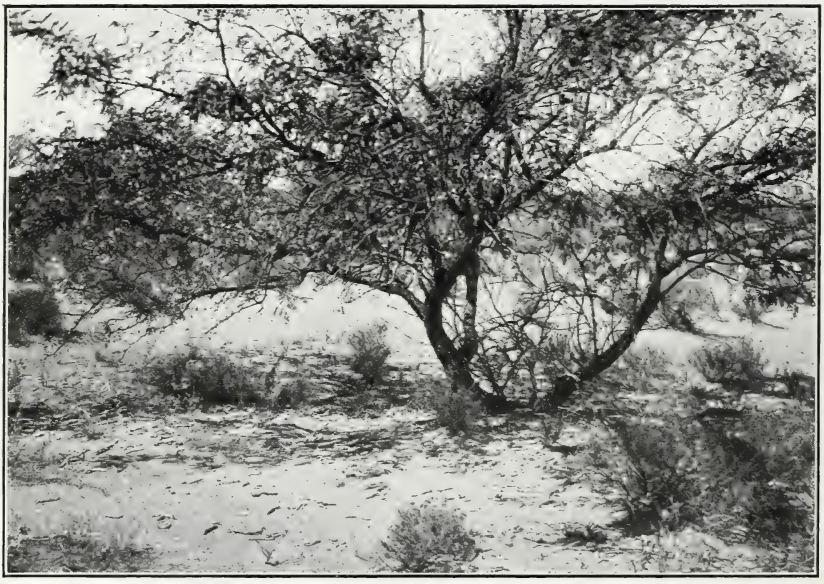

FIG. 2.—A SINGLE MEDIUM-SIZED MESQUITE BUSH ON THE RESERVE, SHOWING ITS CROP OF BEANS ON THE GROUND.

The dried beans from this bush weighed 10¾ pounds. These beans are very nutritious and are eaten freely by all kinds of stock.

FIG. 1.—CONDITIONS IN AN ARROYO, SHOWING HOW THE GRASS RETARDS EROSION AND HELPS TO FILL IN WASHED PLACES ON THE SANTA RITA RANGE RESERVE.

Hundreds of places may be found on the reserve where different stages of this process of leveling up are in progress.

FIG. 2.—THE BOUNDARY FENCE BETWEEN THE MCCLEARY (LEFT) AND MACBEATH (RIGHT) PASTURES IN MAY, 1914, SHOWING THE EXTENT TO WHICH THE FORAGE ON THESE PASTURES IS FED OFF EACH SEASON.

FIG. 1.—AN OPEN SPOT AMONG THE MESQUITE BUSHES ON THE SANTA RITA RANGE RESERVE.

A good stand of grass has been obtained by persistent sowing. (Compare with fig. 2.)

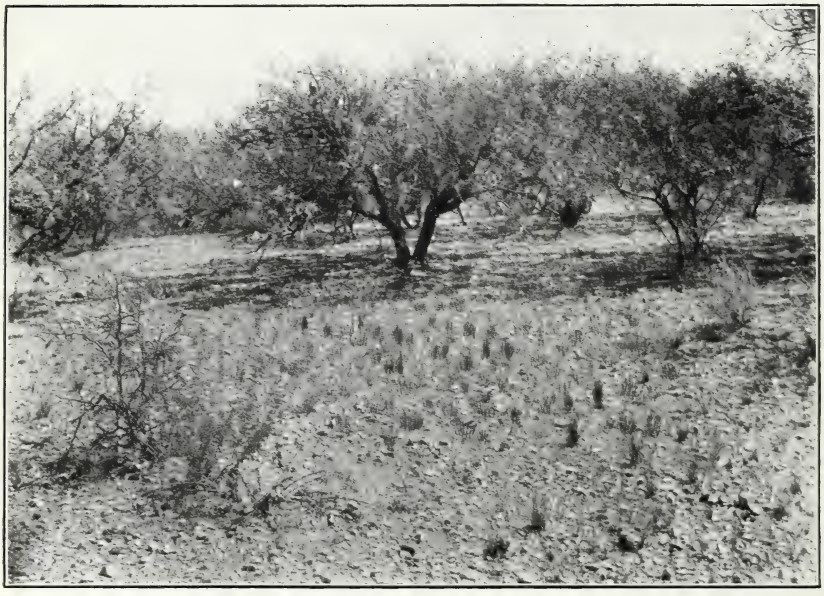

FIG. 2.—A SIMILAR OPEN SPOT, SHOWING THE BEGINNING OF THE GROWTH OF GRASS.

No results were obtained on this spot (which is less than 100 yards from the other) for several seasons, though seeds were scattered each year. (Compare with fig. 1.)

If allowance is made for the facts (1) that these pastured areas produce more feed than other parts of the area under observation, (2) that they are carrying more under the present form of management than they would if an average number of animals were kept on them continuously, and (3) that there is some indication that they are slightly overstocked, it is seen that the results obtained from the pasturing experiments are in reasonably close agreement with the average for the whole reserve derived by other means and presented elsewhere in this bulletin. (See p. 21 et seq.)

MISCELLANEOUS NOTES.

The effects of fire.—The complete protection of the reserve for a number of years has resulted in a rather heavy crop of dry grass, which burns readily, especially in the dry, hot weather of May or June, just before the summer rains begin. Several such fires have occurred, due to lightning, carelessness of passers, or incendiarism. The only serious damage they do is to burn off the fence posts and let the fences fall. These fires are always extinguished as quickly as possible after they start, but sometimes considerable areas have been burned over. Attention has been called to the effect on the mesquite bushes. The spines of the cacti are usually singed off, and some of the stems blistered, and a few are killed. *Opuntia spinosior* seems to suffer more seriously than any of the other species. In June, 1914, occurred one of the largest and hottest fires, which burned over about four sections of the heaviest grass. Along the arroyos where the grass was highest and thickest the mesquite bushes were killed completely in several places, and many were killed back to stumps. The following growing season on the burned area there was a much larger proportion of annuals in the summer collections and a particularly noticeable abundance of one grass, *Bouteloua parryi*, which has not been observed in any abundance recently. It was common in many parts of the reserve in the earlier years of the experiment. Whether or not the burn was responsible for these occurrences the writer is unable to say. The fire was doubtless responsible for a noticeable decrease in the hay crop obtained on part of the burned area this season.[1] Of the grasses, *Bouteloua eriopoda* and *Heteropogon contortus* suffered most, though old stools of *Aristida divaricata* also showed retardation and some killing.

The mesquite bean crop.—An important part of the forage of this region is furnished by the herbage and flowers of the cat's-claw (*Acacia greggii*) and the mesquite (*Prosopis velutina*), as well as by beans of the latter. Two measurements were made of the crop of mesquite beans from medium-sized trees in 1914. The blossoming

[1] See Table IV, p. 24: Proctor's records for 1914.

season of 1914 seemed to be very favorable, but very few trees set fruit. The data as to measurements are as follows:

One tree about 1 mile nearly east of the location marked I on the map (fig. 2), 9 feet high, with a spread of 10 feet, produced as second crop 10¾ pounds of dried beans (Pl. VIII, fig. 2). Another tree near McCleary's house, 9 feet high and with a spread of about 14 feet, produced 10 pounds of dry beans as a first crop. Probably 60 per cent of the trees on the reserve are as large or larger than the two measured.

Erosion retarded.—The process of leveling the land by the action of water, assisted by the growth of vegetation, has been going on ever since the stock were put out of the reserve and the plants commenced to reestablish themselves. It has been carried to completion in some of the shallower arroyos, and the bottoms of the watercourses are entirely covered with plants. The larger arroyos still have well-marked sandy channels where nothing but coarse annual weeds grow, but the grasses are rounding off the banks of such channels and gradually diminishing their width, while in many places they prevent further erosion by growing directly in the narrow cut and helping to hold whatever earth may be washed in by the run-off (Pl. IX, fig. 1).

Seed sowing.—Numerous attempts at reseeding have been made on this range reserve and elsewhere, the results of which have been reported in previous bulletins.[1] Most of the attempts have resulted negatively. Particularly is this true with reference to introduced species, although these have been selected with the best judgment obtainable as to the requirements of the region and the possible adaptiveness of the species tried. It by no means follows that nothing will ever be found that will suit the conditions, and there is believed to be good reason for expecting that some valuable finds of this kind will be made in regions not yet carefully explored with these desires in mind.

The alfilaria, previously reported as seeming to take hold, has since been entirely crowded out by the native perennial grasses. Several annuals that gave some promise have also given way to the native perennials.

Trials of Sudan grass were made at three different places on the reservation in 1914—near MacBeath's house, near McCleary's, and in the large field on the plowed ground (near H, fig. 2). The seeds germinated well at each place, but the young seedlings were not able to bear the dry weather that occurred after the first rains. Plants at MacBeath's which were watered during the first dry spell made a good growth (about 3 feet) and produced some seed. Plants

[1] See Bureau of Plant Industry bulletins as follows: No. 4, reporting results on a small range near Tucson; No. 67, giving later results on the same area; No. 117, treating of methods and results of reseeding in general; No. 177, treating of results on this range.

that were not watered grew about 3 inches high or less. It is very doubtful if a crop of this grass can be grown without irrigation, even on that part of the reserve that receives most water.

Not so unsatisfactory, however, are the results obtained by scattering seeds of the native grasses upon the bare spots, even where the soil conditions are not good. For a number of years it has been the habit of Mr. McCleary to scatter seeds of the local native grasses upon bare spots in his pastures. Since hay cutting has been going on, it has been possible to get seeds in some quantity at the hay baler, and he has taken advantage of this means and has each year scattered seeds in considerable quantity. Many gravelly slopes that would otherwise have remained bare are now grassed as the result of this treatment. (Pl. X, fig. 1.) Other things being equal, this method will get results in the course of two or three years that would occur much more slowly without scattering the seeds over the ground, though difficulty in getting germination sometimes occurs. (Pl. X, fig. 2.) This method of reestablishing the native species is very inexpensive and seemingly warrants the time and effort.

Experiments with sheep.—After the large field had been under fence for a number of years and the crowfoot-grama area had shown considerable improvement, an arrangement was made to try feeding off with sheep that part of it lying north of Box Canyon. A supply of water was developed in the canyon and a small band of sheep (about 1,200 head) was put on the area in the early spring. They stayed on the reserve about 60 days and were under the care of a Mexican herder, just as sheep are handled on the open range. While there was apparently an abundance of feed for such a band, the animals did not improve. As the dry spring and early summer weather began the water supply gave out and it was necessary to move the sheep. The next spring another trial was made in the same way. A small band was put on the reserve. These sheep were in very much weakened condition when they went on the reserve, but they did not recover as it was hoped they would on the abundant dry feed to which they were taken. They were on the reserve from February 22 to May 16, and lambed during the 30 days beginning March 18. In May, as they were leaving the reserve because of failure of the water supply, there were 440 ewes and 260 lambs in the band, and they were all in very poor condition.

The results of these experiments indicate that the grass of this region is not good feed for sheep, because it is too dry at the time of year when sheep need succulent feed to produce milk for the lambs. Dry feed at lambing time and while the lambs are young is unfavorable to the business in several ways, even though there is an abundance of the feed. Since the perennial grasses have dominated most of the better part of the reserve, the production of spring annuals has decreased quite markedly, and the spring feed for sheep is not as

good as formerly. The quantity of feed produced, however, has increased very much, and the change in kind has shown quite conclusively what every stockman already knew, i. e., that the region is better adapted to cattle and horses than it is to sheep. The grazing of these small bands of sheep on the range reserve did not affect the range in any way detrimentally in the short time they were there. It was hardly possible to see where they had been running except about the bed grounds, though the herder's camp was not moved while he was on the reserve.

FUTURE INVESTIGATIONS.

Summarizing the data so far collected on the Santa Rita Range Reserve has not only shown the results obtained, but has pointed out several lines along which further data should be collected by continuing work in progress, and it has also suggested some new lines of investigation.

Besides keeping watch on the rate of spread of the various grass associations mentioned in this bulletin, it is very desirable to devise some way of measuring the productivity of the black-grama association more accurately than has heretofore been possible. Special attention should be paid to its rate of spread in the northwest corner of the reserve. The question of whether it will supplant the crowfoot-grama association at the lower levels is one of great importance, as is the time it will take for the black-grama association to cover any given area.

Some accurate measurements as to the rate of spread of the long-lived perennial grasses like *Heteropogon contortus* and *Bouteloua eripoda* are desirable, as are more data on the productivity of the six-weeks-grass areas. The rate of recovery and factors affecting it on the plowed areas should be studied carefully. Some seeding experiments with the local species should be tried in the extreme northeastern corner where these grasses have been very largely killed out.

Assuming that that part of the recovery pasture lying east of the Helvetia road has about reached its normal productivity, it would seem to be wise to establish an experiment to determine just what the carrying capacity of this area is, by grazing off the forage crop with a definite number of animals that are kept on it all the time, this number to be based upon estimates already obtained from quadrat measurements and hay-cutting records.

SUMMARY AND CONCLUSIONS.

The conditions under which the series of experiments of which this bulletin is a report of progress were carried on are set forth in the introduction. An attempt is here made to summarize the results so far obtained, those reported in previous bulletins being included for the sake of completeness.

Recovery.—It is the unanimous opinion of all who know the region that the carrying capacity of the completely protected area has improved very much over its condition at the beginning of the experiments. There is likewise no doubt that the carrying capacity of the inclosed areas under stock is now greater than that of the adjacent unfenced land of similar character.

Rate of recovery.—Previous publications relative to this project have stated that recovery of that part of the reserve inside the large field and lying above the 3,500-foot contour occurred in marked degree in about three years after inclosure. The improvement in that area since that time has continued, but the increase in productivity has been growing less and less each year, indicating that that part of the reserve has now about completely recovered. The area of increased productivity has been gradually spreading until all parts of the inclosure are now more or less improved. In the opinion of the present writer, that part of the reserve below the 3,200-foot contour may be expected to continue to improve for a number of years more, under protection, and the recovery experiment should be continued at least until such time as complete recovery of this area is obtained.

Some definite answers are now available as to the time necessary for recovery under different conditions. Three years of complete protection gave about three-fourths of complete recovery for the area where crowfoot grama is the dominant grass, at levels of about 3,500 to 4,000 feet, where an annual rainfall of 15 to 18 inches occurs. One inclosed pasture of this type having an area of 794 acres, which has been stocked with horses and burros at the average rate of about 11 head per section, recovered somewhat more slowly than the completely protected area beside it and at the same level, but after 11 years protection is now not appreciably different in carrying capacity from the completely protected area, a condition which has obtained on this pasture for the last two or three years. This would indicate that this pasture recovered under light stocking in about double the time required for the completely protected area. Areas at higher levels might be expected to do at least as well if not better under similar treatment.

Three other areas, 1,065, 1,695, and 1,889 acres in extent, respectively, which have been judiciously pastured with approximately all the cattle they could carry, are known to show better productivity than adjacent unprotected grazing land of the same character; and by their users these areas are believed to have materially increased in carrying capacity under this kind of treatment within a period of 11 years. Table VII and the curves in figure 5 show a gradual increase in numbers carried on the two larger areas. Hence, if these pastures have been stocked to their proper limit all the time and the condition of the pastures has not declined, the curves indi-

cate approximately the increase in carrying capacity under the treatment imposed. The factor of occasional insufficiency of stock water has interfered with the stocking of the other pasture and modified the results. In general, therefore, it may be said that, other things being equal, the rate of recovery in this region varies with the available moisture. With complete protection the better part of this range recovered rapidly at first, large gains being made in the first two or three years, and approached complete recovery in 10 or 12 years. The poorer parts of the range are much improved after 11 years' protection, but are probably not yet completely recovered. Light stocking of the better part of the range with horses (approximately one-third of the stock it could carry) doubtless retarded the rate of recovery, but after eight or nine years this animal factor was negligible. Heavy stocking with cattle has not prevented but has retarded recovery, so that after 11 years the grazed areas are but partially recovered, though their carrying capacity has increased not less than 30 per cent and possibly more in that time.

Reseeding operations.—Practically all attempts to introduce new species of forage plants or to increase the relative abundance of particular endemic species beyond their natural importance in the plant associations of the region have resulted negatively. In a few cases introduced plants like alfilaria or some aggressive annuals have seemed to promise some returns, but in the course of a few years the native perennials have crowded them out. By far the greater number of the species tried have given nothing but negative results from the first.[1] The scattering of seeds of the local native species upon bare ground has proved to be well worth the trouble, since the practice has resulted in the more rapid recovery of such areas. This procedure has also put a crop of grass upon some soils where it was predicted that nothing would grow. The policy of scattering the seeds of the best grasses of a region on the denuded areas is to be recommended to stockmen generally wherever the seeds can be had in any quantity at relatively small expense, as is always the case where range hay is baled. On areas of large size which have been denuded of their best native grasses a seemingly large expense is warranted in order to get seeding plants of such grasses established on the area. Generally speaking, the seeds of native species of this region do not need to be covered, since they are mostly able to bury themselves deep enough to cause germination, at least under favorable climatic conditions.

Carrying capacity.—An attempt is here made to work out an expression representing the average carrying capacity of the whole range reserve, in the belief that this result will apply to a large part

[1] See Bureau of Plant Industry Bulletins 117, p. 22; 177, p. 12.

of southern Arizona and possibly to an even larger area. Records of four kinds have been obtained.

(1) Collections of everything growing upon small measured areas (quadrats) have been made for a number of years in representative parts of the range reserve, and from the weights of the dry material collected the total productivity in terms of pounds of forage per acre has been calculated. These records extend over a period of nine years. From each year's collections an average for the year has been obtained. From these yearly averages something is learned of the rate of improvement of the pasture, and from an average of all records is obtained an approximate value of the average total annual productivity, which is about 1,160 pounds per acre. This figure is obtained by a method that denudes the ground. Stock always get less than this amount.

(2) Records of hay cutting on part of the reserve have been obtained for the past five years on areas varying from 1 to 114 acres. The total area for all seasons from which measurements were obtained was 492½ acres. The average amount of hay obtained is 640 pounds per acre. Three areas, each about an acre in extent, which had the hay cut off for four years in succession, lost in productivity from one-half to three-fourths of what they produced at the start, as the result of continued cutting. The average production of hay on this land is about 70 per cent of the productivity shown by the quadrat collections made on and beside the areas cut over; hence, it is argued that stocking on the basis of an estimated production of more than one-half of the total productivity as obtained from the quadrat measurements would be unwise, since such a policy would tend to lower the carrying capacity below what would be maintenance capacity for the area under stock.

(3) A map is submitted, showing the approximate distribution of the different forage-plant associations of the reserve, and descriptions of the details and possibilities of each are presented. From the quadrat measurements the approximate productivity of each association is obtained. From these figures and the areas of each association a weighted average expression representing the average productivity of the whole reserve is derived. This number, 1,110 pounds per acre, is closely comparable with that obtained as the average of the quadrat measurements alone. Assuming the value of 1,100 pounds per acre as an average total productivity and 50 per cent of that amount as maintenance capacity for the range, then, if the average animal eats the equivalent of 30 pounds of dry feed per day he will need 11,000 pounds in a year, and it will take 10 acres of land to furnish that amount at full productivity, and 20 acres of land at maintenance capacity. Thus we have an average value for carrying capacity equal to 20 acres per head per year, or 32 head per section, for the reserve.

(4) Records of animal-days' feed consumed for a period of five years on about 16 per cent of the best part of the reserve show exactly what this land can do under a certain kind of management. The type of management used tends to make the carrying capacity for this area appear high. The pastured area naturally has the highest carrying capacity of any part of the reserve. The area has probably been slightly overstocked recently. All three of these factors tend to increase the apparent carrying capacity of the area under stock. The figure representing average carrying capacity for $7\frac{1}{4}$ sections (one-eighth of the whole reserve) which have been stocked with cattle is 14.1 acres per head per year, or 45+ head per section. This carrying capacity, for the reasons stated, is considerably above that for the whole range. Just how much too high it is would be very hard to tell. Figures obtained on one of the pastures show that stocking at the average rate of 58 acres per head per year, or 11 head per section, is considerably below the limit of maintenance capacity, since the pasture so stocked is now not noticeably different in condition from adjacent land which has had no stock on it for 11 years.

Miscellaneous data.—Miscellaneous notes on the effects of fire, the effect of protection on the minor relief features of the area, some results of seed sowing, the results of a small amount of sheep grazing, etc., are added, and a few suggestions as to the character of future work are made.

LIST OF PUBLICATIONS RELATING TO THIS SUBJECT.

Range Improvement in Arizona. By David Griffiths. Bur. Plant Indus. Bul. 4. 1901.

Range Investigations in Arizona. By David Griffiths. Bur. Plant Indus. Bul. 67. 1904.

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A Protected Stock Range in Arizona. By David Griffiths. Bur. Plant Indus. Bul. 177. 1910.

The Grazing Ranges of Arizona. By J. J. Thornber. Bul. Ariz. Exp. Sta. 65. 1910.

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